Electrical Engineering

April
1937

Published Monthly by the
American Institute of Electrical Engineers

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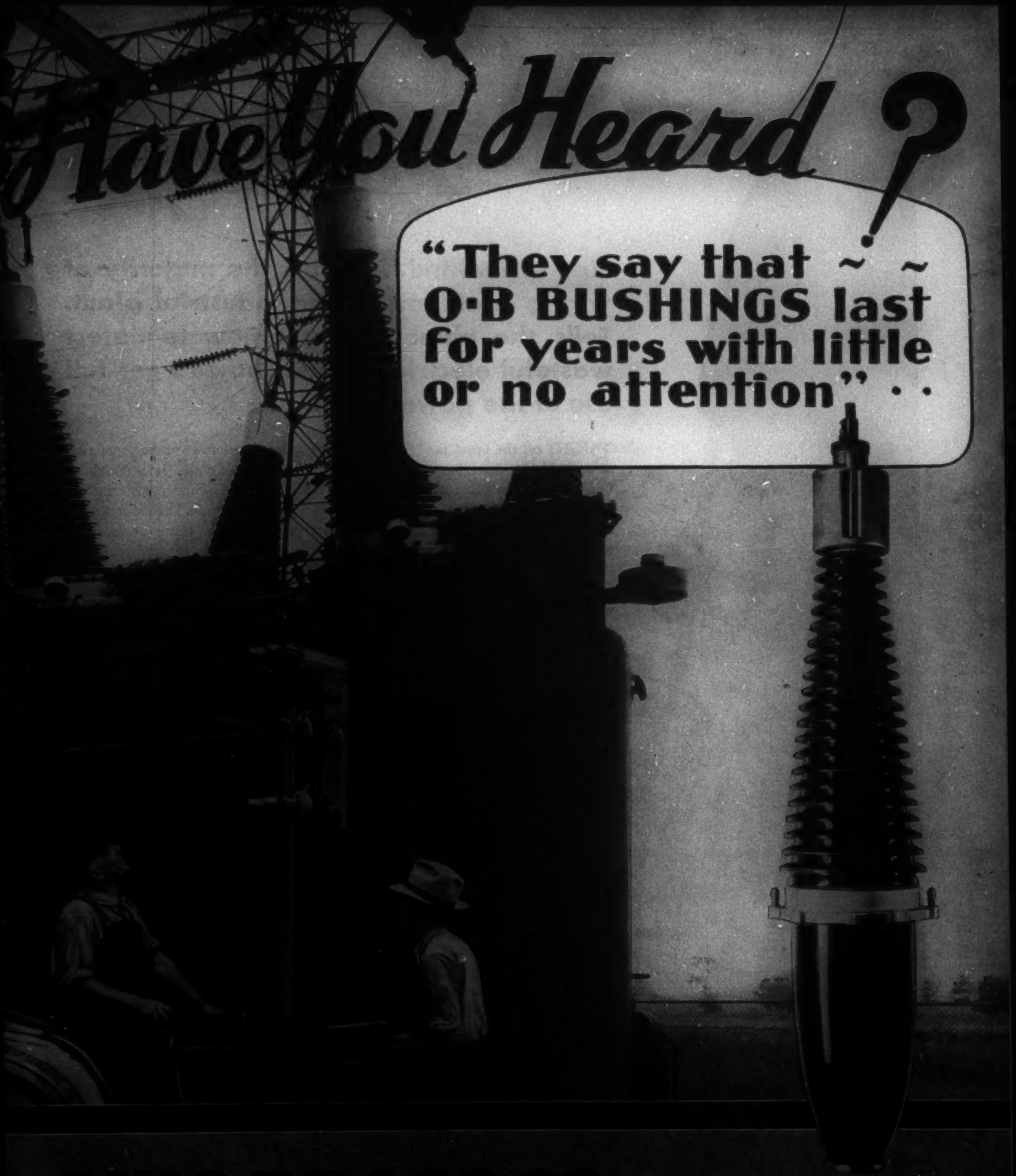
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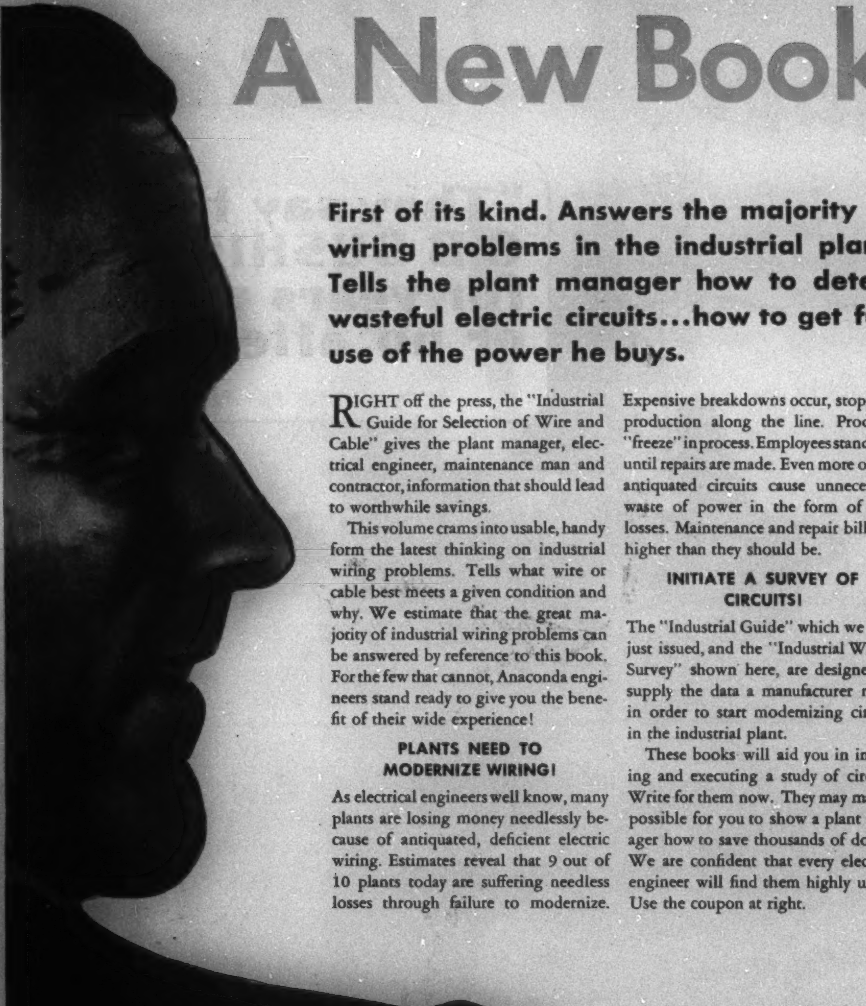

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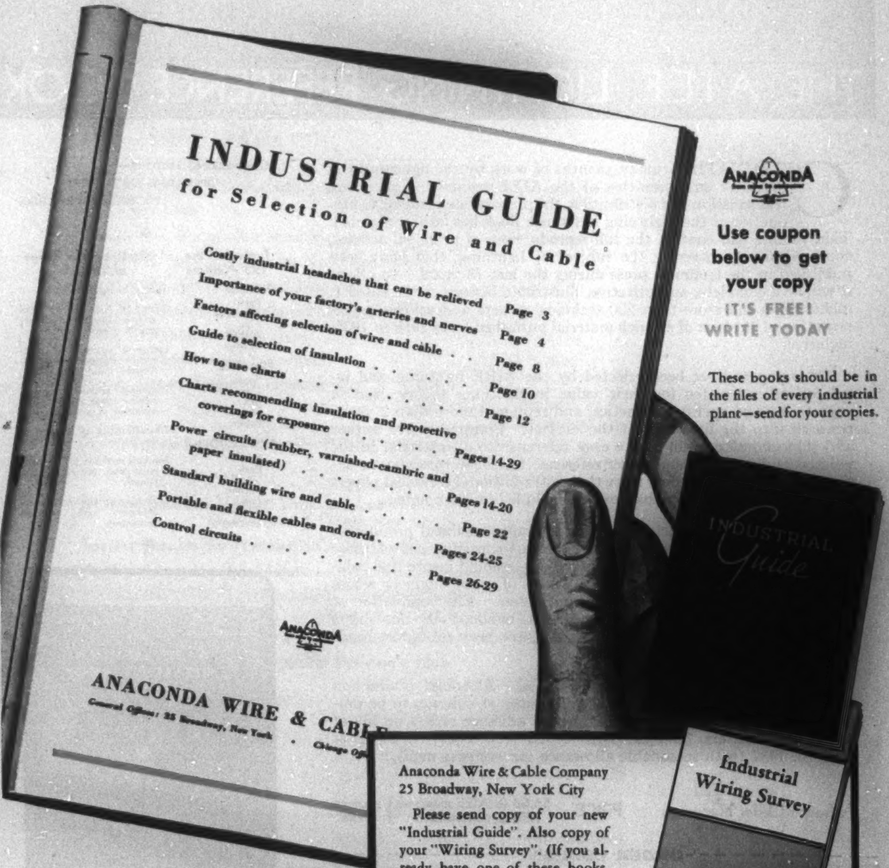

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Power circuits (rubber, varnished-cambric and paper insulated) . . . Pages 14-20
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Announcing

THE A.I.E.E. LIGHTNING REFERENCE BOOK

CULMINATING many months of work by the lightning and insulator subcommittee of the AIEE committee on power transmission and distribution, the preparation incident to production of the Lightning Reference Book has been completed. This volume will contain the full reproductions of principal articles, comprehensively covering the subject of lightning, that have been published in the technical press during the last 18 years. In effect, it will be a complete, authoritative, illustrated history of the subject, including in full more than 200 technical papers and articles representative of the best of all such material published from 1918 to 1935, inclusive.

These papers have been selected by the AIEE lightning and insulator subcommittee for their value in lightning theory, and in engineering and operating practice, and represent more than 2 years' research into the literature of the subject. Comprehensive author and subject indexes will assure easy reference to all material in the volume, and, to facilitate further reference for those who may so desire, these indexes will cover more than 200 additional technical papers of a supplemental nature that are not included in the volume.

The low price (embracing only the actual mechanical production costs)—made possible only by the generous contributions of those who partook in the initiation of this project—should insure this valuable reference volume a place in the hands of every engineer whose work touches upon the subject in any degree. The completion of this project is made possible by the several hundred advance orders from Institute members and others that have been on file at headquarters for some months.

A limited edition only will be published. Although production work already is under way, the actual number of volumes to be produced will be governed by the number of advance orders on file at AIEE headquarters, 33 West 39th Street, New York, N. Y., as of May 15, 1937 (with reasonable allowance for overseas mail).

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- Modern methods of lightning protection, and results obtained
- Technique of laboratory measurements with impulse generators

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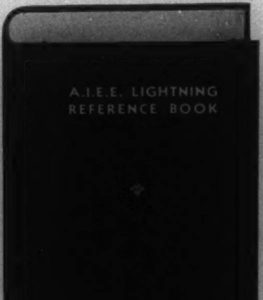

The Lightning Reference Book will comprise some 1550 pages, 8½ x 11 inches in size—a volume of about the same size as the current annual volumes of AIEE TRANSACTIONS and similarly bound in durable green cloth. It is expected to be ready for distribution in July 1937.

●

This is the final opportunity for interested persons to assure receipt of copies. Send your order promptly. The accompanying coupon is provided for convenience.

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Ready for distribution in July

Electrical Engineering

Registered U. S. Patent Office

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The Cover

Tapping an electric furnace in the Canton, Ohio, plant of the Republic Steel Corporation

VOLUME 56 NUMBER 4

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An inspection trip to the $375,000,000 Grand Coulee project on the Columbia River, about 92 miles from Spokane, Wash., is being included on the program of the Institute's 1937 Pacific Coast convention to be held in that city, August 30–September 3. It is planned also to include one or more papers dealing with the engineering features of the project. At the left is reproduced a photograph taken March 8 especially for ELECTRICAL ENGINEERING by the U.S. Bureau of Reclamation, showing the status of construction on that date. In the foreground is the completed foundation for one end of the dam which will rise to a maximum height of 550 feet and will contain 11,250,000 cubic yards of masonry. The entire project includes construction of a dam, a 2,700,000-horsepower power plant, and a pumping station on the Columbia River; a reservoir in Grand Coulee; main irrigation canals; and water distribution system on the project lands.

High Lights

Engineering Education. "American engineering colleges have a great responsibility in meeting the demands of the times so that their graduates will be capable as engineers and will also have . . . well-rounded ethical standards and broad interests. . ." So says a recognized authority in outlining current practices and trends in engineering education (*pages 414–17*). Careful consideration should be given to that phase of engineering education, and professional development, which follows the award of the bachelor's degree, according to another well-known educator (*pages 418–19*). Graduate courses for engineers are now being offered on a part-time basis by several educational institutions in Chicago, Ill. (*pages 417–18*). In order that the engineer may learn to write and speak with facility, it is suggested that the study of English should commence as soon as the student enters college and continue until he graduates (*pages 419–20*).

Alternator Regulator. A simple electronic voltage regulator for alternators, utilizing 2 mercury-vapor control tubes combined with a small inductance, capacitance, and resistance has been developed. Its sensitivity and operating speed are said to be comparable with those existing electronic regulators of more complicated design (*pages 462–4*).

Economics and Business Courses. To stimulate the interest of student engineers in economic problems, a brief but fairly comprehensive course in industrial economics and business methods is advocated in place of some of the highly specialized technical courses now included in engineering-college curricula (*pages 446–54*).

End-Winding Inductance. Formulas for calculating the end-winding self-inductance and leakage inductance of a salient-pole synchronous machine are given in a paper in this issue. An effort has been made to indicate the nature and consequences of the assumptions involved (*pages 355–61*).

Magnetic Fluxmeter. To provide means for continuous measurements of somewhat varying magnetic flux in air gaps, a fluxmeter employing 2 bismuth resistance elements (the resistance of which changes with changes in the flux) has been developed (*pages 441–5*).

Ground Faults on Power Systems. An extensive survey of faults to ground on representative power systems in different parts of the United States is recorded in this issue. (*pages 421–8*). Data on fault resistance obtained in this survey also are given (*pages 428–33*).

Automatic Oscillograph. Analysis of system disturbances alone may not justify the use of an automatic oscillograph, but this instrument may also be used to locate faults on transmission circuits, and for testing relays controlled by carrier current (*pages 438–40*).

Oxidation in Insulating Oil. A series of studies of accelerated oxidation in a highly refined paper-cable insulating oil is reported in this issue, with particular reference to the correlation between oxidation and electrical properties (*pages 465–74*).

Electricity on Aircraft. The use of electricity on aircraft has increased to such an extent that the wiring diagrams of modern planes are beginning to resemble those for electric power generating stations (*pages 406–10*).

Voltage Drop. Connection of load to only 2 phases in open star in a delta-star distribution network may sometimes be necessary; voltage regulation requires that the load be divided correctly, which may not mean equally, on the 2 phases (*pages 434–7*).

Elihu Thomson Dead. One of the last of the original group of great electrical pioneers, Elihu Thomson died March 13, 1937. He was a charter member of the AIEE and its fifth president (*pages 482–8*).

District Meeting at Buffalo. An interesting program of varied attractions has been planned for the North Eastern District meeting of the AIEE to be held in Buffalo, N. Y., May 5–7, 1937 (*pages 489–91*).

Summer Convention. Tentative plans for the Institute's 1937 summer convention to be held in Milwaukee, Wis., June 21–25, include 10 technical sessions and 1 general session (*page 491*).

Auditory Perspective. Reproduction of orchestral music in auditory perspective has been demonstrated out-of-doors with the orchestra present (*pages 412–13*).

Prizes for Papers. Rules for the award of Institute prizes for technical papers have been revised (*page 492*).

DISCUSSIONS

Appearing in this issue are discussions of the following papers:

A-C Characteristics of Dielectrics—II—Banos . . 477

Dielectric Strength of Transformer Insulation—Bellaschi & Teague 479

Statements and opinions given in articles and papers appearing in ELECTRICAL ENGINEERING are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). ¶ Copyright 1937 by the American Institute of Electrical Engineers. Number of copies this issue—20,850.

Electrical Engineering

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The President on Membership

At least once each year, the president should discuss with the members the subject of membership; for without members there could be no organization, and our fundamental purposes would be impossible of accomplishment. The major accomplishment of the Institute results from the voluntary service so willingly rendered by the national and District officers and committees, the Section's officers and committees, and the authors of the technical papers—a service much greater than, and in addition to, their financial support. However, a great work cannot be accomplished without expense, and funds are necessary to meet these expenses.

The booklet "Membership" by Everett S. Lee, chairman of the finance committee and past-chairman of the Section and membership committees, gives a clear picture as to the advantages of Institute membership, the funds provided by the members, and how they are wisely expended to "advance the theory and practice of electrical engineering and the allied arts and sciences, and to maintain a high professional standing among the members." It is quite unnecessary for me to endeavor to add to this picture.

A society is exactly what its members are, and I shall never be satisfied until every qualified and interested electrical engineer in America is a member of the Institute. The larger the number of qualified engineers who support the organization by their membership, the greater is the prestige of the society and the wider is the opportunity for service to the profession through an intelligent direction of the personnel and use of the funds which they provide.

I have carefully considered the motives which actuate an electrical engineer in applying for membership, and it seems to me that they can be classified in 2 groups.

A. Selfish Interest

1. A desire to be one of a distinguished group.
2. An interest in our technical activities.
3. A desire to advance his professional standing.
4. A desire to broaden his ability through presentation of his ideas and discussion of the ideas of others.
5. The seeking of an opportunity for acquaintance and fellowship with others in their profession.

B. Unselfish Interest

1. A desire to advance the prestige and standing of his profession.
2. The wish to support an organization offering to the younger engineers, with whom he is associated, opportunities for development and advancement in technical knowledge.
3. The desire to be associated with and participate in the activities of a society devoted to service to the profession.

The membership may possibly be grouped in the following classes:

Class 1—*Sustaining.* Those, who in addition to their financial support, largely participate in organization activity, technical activity, student activity, and Section activity.

Class 2—*Participating.* Those who give financial support and attend the meetings and conventions.

Class 3—*Silent.* Those who render financial support and are interested, but do not participate.

Class 4—*Indifferent.* Those who give only financial support.

Class 5—*Dissatisfied.* Those, who through lack of information, lack of participation, or lack of consideration, feel that the organization is not effectively carrying out its purposes.

The first group is the most valuable, for in this group are the most interested members who consider membership in the AIEE a real privilege. It is the constant aim of the officers to transfer those in groups 3, 4, and 5 into groups 1 and 2; but the greatest factor in this desirable transfer is the member himself. Those who contribute most and participate most largely are invariably the most interested. From a very active member I have seldom heard any complaint as to the dues he pays, although he may logically suggest how his dues can better be expended.

Membership is one of our most important activities. It is not the purpose of the membership committee to argue or cajole an engineer into applying for membership; rather to inform him as to our purposes and aims, and draw to his attention the privilege and duty that is his if he is qualified.

I feel that the membership committee should give particular attention to the electrical engineers connected with companies using, but not manufacturing, electrical equipment, and in this they should be aided by the technical program committee. The fundamental purposes of the Institute would be greatly furthered by an increased membership in this group.

Would any engineer desire to see the activities of the professional societies discontinued? Does he wish others to carry on the work of which he should be a part, or does he wish to do his share? If, due to circumstances, he cannot be in class 1, how much greater is his obligation to be at least in class 3. If he feels that the society's activities should be modified, should he not join and within the organization lead the way to higher accomplishments?

The most powerful force toward increased prestige and increased opportunity for service through increased membership, is the attitude and co-operation of those who are now members. Each individual member should do his part. As expressed at the recent winter convention, our aim for 1937 should be to advise every qualified electrical engineer as to our aims and purposes, and invite his assistance in reaching our objective.

A M MacCutcheon

United Air Lines

Electricity Aloft

By S. PAUL JOHNSTON

EDITOR, AVIATION

Apart from the more obvious uses of electrical devices for aircraft communication and navigation, electricity is playing an increasingly important rôle on board modern airliners.

THE PROBLEM of electricity on aircraft has changed materially over the past 15 years. From a necessary evil whose sole function was to ignite explosive charges in engine cylinders, its use has become a question of first-rate importance in the design and operation of the modern airplane.

In 1918, embryo pilots in the Army Air Service used to sit up nights over the "complications" of the electrical circuits on the old Curtiss "Jennies" then in use. The "complications" consisted of a single magneto, 8 spark plugs, a simple "on" and "off" switch on the dash, and about 25 or 30 feet of wire.

By contrast, a modern military bomber, by no means a large airplane as ships go today, takes some 1,200 feet of wire to connect its various circuits. The large transport illustrated at the head of this article, which is known as the Douglas type *DC*-3 plane, and which is now in active production requires between 5,000 and 6,000 feet. Estimates for next year's 40-passenger machines show wiring requirements of over 18,000 feet per ship! The wiring diagrams are beginning to resemble the hookup for a central station or an automatic telephone exchange.

It would take many pages to examine in detail all the steps that lie between the old wartime planes and the modern passenger transport, electrically speaking. However, a few of the high spots might be touched upon to show that, although there are many special problems, basically the matter of the design and installation of the electrical equipment is not so different from the sort of thing with which, as a group, electrical engineers are already familiar.

Probably one of the earliest of the electrical problems on aircraft was the addition of the radio. But a detailed discussion of radio for communication and navigation is beyond the scope of this article. It may be pointed out in passing that beginning with the very simple wartime receiver and rudimentary transmitter, the equipment has been developed to the point where the new transports soon to be in operation will carry no less than 8 or 9 different radio sets of one kind or another, possibly including apparatus for facsimile reception and transmission and for "absolute" altitude determination. Each such installation costs many thousands of dollars, and adds several hundred pounds of weight to the airplane. Also, the power requirements of the radio are constantly increasing. Today the average transmitter has an input of 50 watts. Tomorrow it probably will be considerably greater.

Lighting

Toward the end of the World War night flying began, and from early postwar mail days has been developed to the point where now flying is done at night as casually as in the daytime. This brought with it a number of lighting problems, apart from the question of lighting airports and airways—an important subject to electrical engineers, but also outside the bounds of the present discussion. Earliest solution to the emergency night landing problem was the carrying of a couple of open magnesium flares attached to the wing tips. This soon proved unsatisfactory, as well as dangerous, and the electric landing light came into being. Clearly, too, some form of navigation lights was necessary. Today, every commercial airplane must be

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Essentially full text of an address presented before the transportation group of the AIEE New York Section on January 14, 1937.

equipped with powerful headlights for landing and also the familiar red, green, and white running lights.

Instrument-board lighting became of first-rate importance. The boards themselves have become immeasurably more complicated. Pilots must be able to see each instrument quickly and clearly. All sorts of direct and indirect lighting arrangements have been tried, including a development involving ultraviolet radiation. One airline has been studying the development of the argon light which projects an invisible ultraviolet ray. This ray is directed at radium-painted instrument dials and produces a brilliant glow. In total darkness the "black light" cannot be seen except for the effect it has on the radium dial faces. But even the best so far discovered still leaves something to be desired. A further complication arises from the fact that the intensity of the illumination must be varied at will by the pilot in order that the intensity of light in the cockpit will always match that outside so that his eyes do not have to adjust themselves when shifting from distant objects to the instruments and back again.

The lighting of passenger cabins is a special problem. Not only must general illumination be provided, but also individual reading lights, on separate circuits, must be installed at every seat, or in every berth. Toilets and washrooms, galleys, coat closets, mail pits, and baggage compartments must all have adequate lighting with separate controls. Warning lights in the pilot's cockpit indicate that all passenger and cargo compartment doors are properly closed and secured.

Miscellaneous Devices

The dictates of passenger comfort have made necessary the provision of devices unthought of 15 years ago, as the accompanying pictures show. The galleys on the new ships will be provided with electric ranges for cooking—hot plates and grills. Coffee percolators and electric refrigerators also will appear. The latest washrooms are providing electric razors for the convenience of male passengers. Possibly air conditioning is in the offing.

United Air Lines

Interior of "Skylounge" Mainliner

Other electrical devices have already appeared and will continue to take on new forms as ships become larger. For years there has been complete call-buzzer service from passenger seats and from the cockpit to summon steward service. It was only one short step beyond that to a complete telephone system to all parts of the ship, a convenience that has already put in an appearance. The illuminated sign to warn of an approaching landing and to suggest the use of seat belts is commonplace. Then, since pilots are human and might sometimes forget to extend the retracted landing gear before settling down on a field, automatic warning devices that light red targets on instrument boards, or sound a warning horn behind the pilots' heads, or both, are now installed as regular equipment. All these are electrically operated and further complicate the maze of wiring on the modern airplane.

Engine Equipment

The electrical problems connected with the engines themselves have become tremendously complicated. Ignition is still from magneto, but a much more powerful and dependable machine than those fitted on the old Curtiss *OX*-5 engines of 15 years ago. But where the wartime engines generally had only one, each modern aircraft engine has a complete dual system—2 magnetos, 2 complete sets of wiring, and 2 spark plugs per cylinder. There has been some discussion recently over the advisability of having 3 complete units per engine. Apart from duplication, the ignition has been further complicated electrically because of the presence of radio on aircraft. It is obvious that an ignition system but a few feet away from a highly sensitive radio receiver will cause trouble unless the former is electrically shielded. Complete metallic enclosure for every inch of ignition circuits is the only possible solution. This is not as simple as it may sound, and has been a source of no end of trouble that has not yet been completely overcome.

Even after many years of development, the spark plug is still a source of trouble and annoyance. The modern trend toward taking all possible power out of engine cylinders at high altitudes has opened new mechanical and electrical problems with plugs that were not thought of several years ago. New plugs are now coming into the market, however, that promise relief from present difficulties.

Starting engines 15 years ago was simply a matter of brawn. It was no problem (except to get clear without being hit on the head by the propeller) to "swing" a 90-horsepower engine. Starting a 1,000-horsepower motor is quite a different thing. Inertia starters energized by an electric motor, or direct-cranking electric starters are to be found on most ships today. The bigger the engines become, the larger the starters, and the greater the power required to operate them. All this is bad enough when only one engine is involved. Most ships today have 2 engines. Tomorrow they will have 4—day after tomorrow, 6 or 8. Furthermore, the old single engine was in the nose of the ship. Multiple engines are commonly mounted along the wings where control for starters must be remote, connections complicated.

Because of the remote location of engines there are a number of other operations that can best be done electrically. Obvious is the measurement of temperatures at various parts of the engines by remote-reading thermocouples. Electrical gauges have been devised to show the level of fuel in tanks. Electric tachometers measure engine speeds in cockpits so far away from engines that mechanical drives would be too heavy and impractical. Engines may be accurately synchronized electrically, by matching up the phases of small alternators directly driven by each power plant. Lubricating oil in remote tanks may be warmed to operating temperatures before starting by immersion heaters permanently fitted. Certain instruments are kept free from accumulations of ice and snow by small electric heaters.

One of the latest electrical applications is the continuous indication of fuel-air mixtures in engine carburetors by analysis of the composition of exhaust gases in the exhaust manifold. The Cambridge Aero Mixture Indicator (now installed as regular equipment by most of the major airlines) operates on the thermal conductivity principle incorporating a Wheatstone bridge. The electrical characteristics of one leg of the bridge change with changes in the thermal conductivity of the surrounding exhaust gases, which, in turn, becomes a measure of the quantity of carbon dioxide in the gas. The latter, in turn, is a function of the fuel-air mixture supplied to the carburetor.

Every ship today where performance is an element is fitted with controllable-pitch propellers. The most common type is the hydraulic control developed by Hamilton-Standard of Hartford, Conn. Coming onto the market now, however, is a new electrically driven type introduced by Curtiss-Wright. Changes in blade pitch are made by a small electric motor mounted in the propeller hub and connected to the blades through gears with a very high reduction ratio. Power is supplied to the motor through a pair of slip rings and brushes. An automatic electrical governor has just been developed for this propeller so that it turns at constant speed regardless of power developed at the shaft.

Retracting Units

There are a number of other electrical applications that have been developed through what may be called aerodynamic or operational considerations. For high speed and maximum efficiency an airplane must be "clean," that is, nothing must be permitted to project into the air stream that can possibly be withdrawn inside the smooth contours of the machine when in flight. This accounts for the present practice of retracting the landing wheels, wing tip floats (on flying boats), landing lights, certain radio antennas, and other projections while in the air. Today the field is divided between hydraulic and electrical mechanisms to accomplish these retractions, but, as the size of airplanes increases (and the trend is all in that direction) electric drives will probably predominate. Even if the actual operating elements are hydraulic, the pumps supplying the liquid under pressure will undoubtedly be electrically driven.

Ships that are "clean" require some sort of "air brake" to slow them down to a reasonable speed for safe landings. The brakes usually take the form of a flap under the trailing edge of the wing that may be pulled down at a sharp angle to the air stream. Such flaps, on large planes, are either hydraulically or electrically operated; but, as with the wheel retraction, as size increases, the electrical drive will probably predominate.

"De-icers" are a part of the winter equipment of modern commercial aircraft operating in northern countries. It is out of place here to describe their action, but sufficient to say that certain necessary control valves and air compressors are electrically driven.

The future holds other probabilities. As airplanes become very large—and indications are that the limit where these changes will have to be made is now approaching—it will be impossible for a pilot, unaided, to operate the flying controls. Some form of relay-operated servomechanism will have to be developed to move the control surfaces at the will of the pilot, just as a steering engine functions in a large steamship. Again, both hydraulic and electrical mechanisms are possibilities, but the probabilities favor the electrical. No ship has yet been built incorporating these ideas, but studies have already been made looking toward the future.

Also, as ships get larger, other power auxiliaries will be needed. Hoists will be needed for lifting cargo, for engine changing, for operating gang planks, for weighing anchors, and for a host of other things not yet thought of. For all such, the logical drive will be electrical.

Power-Supply Problem

Doubtless the question has already occurred as to where the power is to come from to operate these many electrical devices. To date, the standard source of power on aircraft has been the ordinary storage battery—not exactly "ordinary," however, for the requirements of minimum weight, compactness, and high output have forced the development of special batteries. The average battery for transport planes today is $14^1/_2$ inches long, $7^1/_4$ inches wide, and $11^1/_4$ inches deep. It can supply about 88 ampere-hours at 12 volts and weighs about 70 pounds. One company has recently placed on the market a new battery having the same over-all dimensions and said to be capable of supplying 105 ampere-hours. Over-all dimensions are important because all modern transports have been built with a battery compartment of a standard size, and fundamental changes in design would be necessary to accommodate larger sizes.

Generators, driven directly by the airplane's engines, supply a certain amount of recharging to batteries in flight, but the demands are usually so high that the drain on the battery exceeds the replacement, and it is common practice to remove batteries from every airplane at the end of every run and send them to the charging room. One of the last servicing operations before departure from a terminal station is to install a fresh battery in the plane.

It is good practice, also, in order to relieve the plane's battery of the heavy drains occasioned from starting engines to provide independent starting power on the ground. This may take the form of mechanical power applied from an outside mechanism (electrically driven, to be sure) or from providing starting batteries on small portable carts that may be connected into the plane's electrical circuits by means of cables and a plug in the body of the ship.

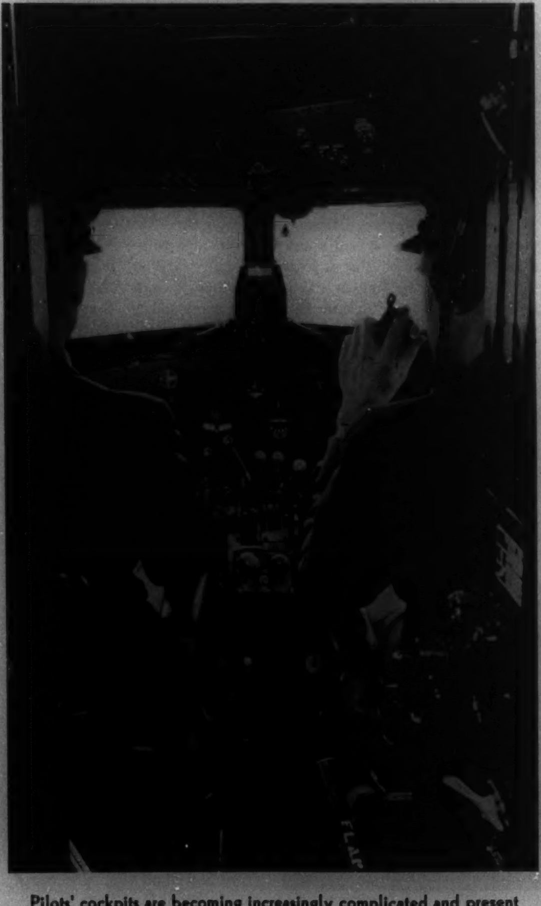
Electrical equipment, however, has been added faster than battery design could keep up. Even for present requirements, one battery is hard pressed to do the job. As soon as it becomes necessary to think in terms of 2 or 3 batteries on each plane, it becomes worth while to examine other possibilities to see if something else may not be found to yield the required power for the same weight carried. One answer is already in sight. It seems not unlikely that the large plane of the future will carry its own independently operated electrical power plant—a gasoline-driven motor-generator set delivering 110-volt alternating current.

Equipment already has been designed, and shortly will be commercially available in the form of small 4-cylinder air-cooled gasoline engines, to deliver at least 15 or 20 horsepower at altitudes up to 20,000 feet to drive a-c generators and other auxiliaries. These will be completely self-contained, will be installed in some convenient out-of-the-way place in the airplane (probably in one or more of the engine nacelles), and will be remotely controlled. Besides driving the generators they will also operate a number of auxiliaries now mounted on the main engines, thus improving over-all reliability by removing from the airplane's power plants a number of sources of potential failure. In addition, the exhaust heat from the small engines will furnish ample heat for maintaining proper temperatures in passenger cabins at high altitudes.

Another important feature is that such independent units may be kept in operation when the airplane is standing on the ground. Power is required in increasing quantities for use on board during stops, and it is obviously more economical—and safer—to keep the small plant running than to attempt to keep one of the main engines turning over to drive generators.

One of the first questions that came up in the consideration of independent a-c power plants was the matter of frequency. There would have been some advantages as far as operations on the ground were concerned in selecting 60 cycles. It would thus have been possible to plug into the circuits at the average field when standing in stations or in hangars. Weight considerations, however, ruled out 60 cycles. Familiar, of course, are the effects of higher frequencies in reducing the weight of iron in motors and transformers, so that the preference at the present time for equipment operating at 800 cycles is immediately clear. Some study has been given to intermediate frequencies, but the trend seems definitely toward the 800 level.

Once the break has been made away from the present 12-volt battery-operated system with its limitations, it is difficult



Pilots' cockpits are becoming increasingly complicated and present difficult lighting problems. This is on a Douglas DC-3 plane

to predict how far electrically operated auxiliaries on aircraft may go. Once a really adequate source of electric power is assured in the form of an independent motor-generator set, designers may really begin to explore the possibilities of the field. They doubtless will find many new uses for electricity on airplanes that no one has yet dared to think about.

Some Special Problems

So far, many points of similarity between the electrical problems on aircraft and the problems with which most electrical engineers are familiar have been considered. In closing, a few of the problems that are distinctly special because of the peculiar conditions under which aircraft operate may be mentioned.

First, and always foremost, is the question of weight. In other fields of transportation, weight control is a secondary consideration. In aircraft design it is all important. All additions to the tare weight of any airplane are immediately reflected in reduced range or in loss of pay load. The gross weight of an airplane for any desired level of safety or performance is fixed. Clearly, then, increases in the weight of the ship's structure or auxiliary equipment must come out of the fuel supply or out of the cargo. Each electrical unit, then, becomes a separate and distinct design problem, and must be treated as such. The separate load requirements must be calculated accurately and provided for without margins beyond those dictated by good sense for safe operation. For example, it will not do to install a $^3/_4$-horsepower motor simply because it happens to be on hand, when the job, with all allowances, requires $^5/_8$ horsepower. The difference in weight may seem negligible in each case, but the cumulative effect may run into many pounds. It is thus impossible to stock a few items to use over a wide range of requirements as is common industrial practice. Each item must be looked upon as distinctly special.

Likewise, mountings cannot be multiplied by 2 or by 3 just to be safe. Here, especially is weight control important. All fittings connecting electrical appliances to the main structure must be calculated down to the last ounce consistent with safe operation.

The selection of operating speeds for electrical equipment is dictated by weight considerations. In general industrial work, speeds are selected that will best fit certain desired operations. In aircraft, the highest practical operating speeds are selected to save weight. For example, an inertia-type engine starter turning at speeds up to 3,600 rpm may require a 20-pound flywheel to do a certain job. If the speed is increased to 12,000 rpm a wheel weighing between 2 and 3 pounds will produce the same energy. The same general considerations are true for the design of many items.

Because of the inherent characteristics of airplane structures, all the equipment mounted on them is constantly exposed to vibration over a wide range of frequencies. The ruggedness of design demanded by this type of treatment is not conducive to weight-saving, but again, the corners must be cut as closely as possible consistent with satisfactory operation. It is obvious, too, that such conveniences as delicately balanced relays and automatic switches cannot be used, although they often would be very helpful.

Another difficulty arises from the wide range of temperature to which aircraft is subject within a relatively short time. Thus an airplane may take off from sea level under moisture-saturated tropical conditions, and 25 or 30 minutes later be flying at some subzero condition at an altitude of 15,000 feet. Not only the temperature drop but the condensation may cause plenty of trouble in the electrical apparatus.

Then the wiring of all the electrical equipment is a problem in itself. Fifteen years ago, going back to wartime planes, a bit of open wiring on cleats did the job. Not so today. Everything must be run in metal conduit. All wiring and conduit must be mechanically strong to withstand the vibration. It must be electrically good to avoid possible fire hazard and to provide adequate radio shielding. In many places positive-action quick-detachable connecting plugs must be provided to permit quick replacement of certain units such as engines, whole radio sets, or individual instruments.

Space has not permitted more than a hasty review of the several problems of the electrical equipment on modern aircraft, but it is hoped that they have been demonstrated to be of vital importance to the development of our latest transportation industry, and that they are worthy of the attention of the best electrical talent in the country.

Westinghouse Photo

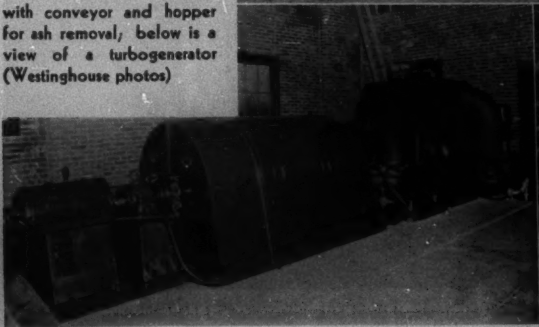
Newark (N.J.) Airport at night

Power From Waste Heat of an Incinerator

A new incinerator plant at Providence, R. I., uses the hot gases from a 5-cell incinerator with a normal capacity of 160 tons of refuse per 24 hours to generate steam in a 700-horsepower boiler at a pressure of 200 pounds per square inch. The steam is used in a 1,250-kw turbogenerator which furnishes power for operating the city's sewage disposal plant and will furnish power for a sewage pumping station now being motorized. A duplicate boiler and turbogenerator assure continuous service. The view above shows wrapped garbage and refuse being dumped into the 1,000-cubic-yard storage pit. At the right is shown the exterior of the building, with conveyor and hopper for ash removal; below is a view of a turbogenerator (Westinghouse photos)

(Above.) An electric crane with $1^1/_2$-cubic-yard bucket lifts refuse from storage pit to charging bin

(Below.) Stoking the furnace; gates operated pneumatically meter the refuse. Air is supplied by a turbine-driven forced-draft fan and is preheated



Sound Reinforcing System for Hollywood Bowl

A NEW demonstration of the potentialities of the reproduction of orchestral music in auditory perspective was given at the Hollywood Bowl in California last August, when music reproduced in this manner was heard for the first time out-of-doors with the orchestra present. The occasion was a concert presented by Paramount Pictures with Leopold Stokowski acting as the conductor.

Reproduction in auditory perspective was first demonstrated in 1933. Music played in Philadelphia, Pa., was picked up by microphones, amplified, and transmitted over 3 special telephone circuits to Washington, D. C., where it was again amplified and reproduced by means of 3 huge loud-speakers. The equipment used in this original demonstration was described in a group of papers published in the January 1934 issue of ELECTRICAL ENGINEERING. The characteristics of this equipment were such that the entire frequency and volume range of the most exacting orchestral and vocal music could be reproduced without impairment of quality. The spatial arrangement of the microphones and the corresponding arrangement of loud-speakers was such as to provide substantially perfect auditory perspective. Both the original equipment, and that used in the Hollywood demonstration was developed by the Bell Telephone Laboratories, New York, N. Y.

The Hollywood Bowl is a natural amphitheater situated in a hollow surrounded by low hills. Oval in form with the stage at the lower end, its tiers of seats rise in curved rows up the sloping hillside at an inclination of about 12 degrees. It seats 22,500 persons. The orchestra plays in a large conical sound-reflecting shell on the stage. This shell raises the sound level effectively in the front and central portions of the seating area but not adequately in the side and back sections.

To correct these inequalities in sound distribution and to increase the general level of the music throughout the bowl a multichannel reproducing system was installed. This system also offered the additional advantages that (1) special effects could be obtained by changing the volume and sound quality with manual controls and (2) the loudness of the singers or solo instruments could be increased relative to that of the orchestra.

In providing such equipment for the bowl, conditions not previously encountered in indoor auditoriums had to be met. Since no walls or ceiling were present to reflect sound, arrangements had to be made to direct all the low as well as the high frequencies toward the audience. Moreover, since the loud-speakers had to be placed near the orchestra to create the illusion that the sound all came from the orchestra, care had to be taken to prevent the sound from the loud-speakers from feeding back into the microphones, which would cause singing. These and similar difficulties were overcome by using new equipment particularly designed for the demonstration.

The general plan of the system as installed was to provide 3 microphone positions in front of the orchestra: one at the left side, one in the center, and one at the right side. A separate amplifier channel of high power was provided for each of these positions and the output of each channel was connected to separate loud-speakers mounted above the orchestra shell in positions corresponding to the microphones. Six microphones were used on the 3 channels. Two were connected in parallel on the left channel to give a satisfactory balance for the cellos, harps and bass viols, because the microphones had to be placed close to these instruments to avoid feedback. Two were located at the center so that one would be available to switch in instead of the regular microphone for vocal soloists. At the right, in addition to the regular microphone, there was an extra one out in front of the shell. This was used for harp and cello solo numbers instead of the regular microphone. The volume controls were located in the center of the seating area about 300 feet back from the shell, and at this position the gain of all 3 channels could be varied by one control. When the soloist's microphone

View of Hollywood Bowl after installation of loud-speakers

Includes essentially full text of an article by A. R. SOFFEL of the Bell Telephone Laboratories, Inc., New York, N. Y., published in the March 1937 issue of *Bell Laboratories Record*.

was switched to the center channel, however, a separate volume control was provided for it so that the level of the voice could be changed independently of that of the orchestra. Quality control made it possible to accentuate the low frequencies and temper the very high frequencies, and an equalizer compensated for the characteristics of the loud-speakers, microphones, and air-transmission path. The amplifiers were adjusted to keep the system below the "singing" point at all times. The acoustic power output of the side channels was 200 watts per channel and that of the center channel half that capacity.

Rear of orchestra shell showing bridge structure erected to hold the $2^{1}/_{2}$ tons of loud-speakers

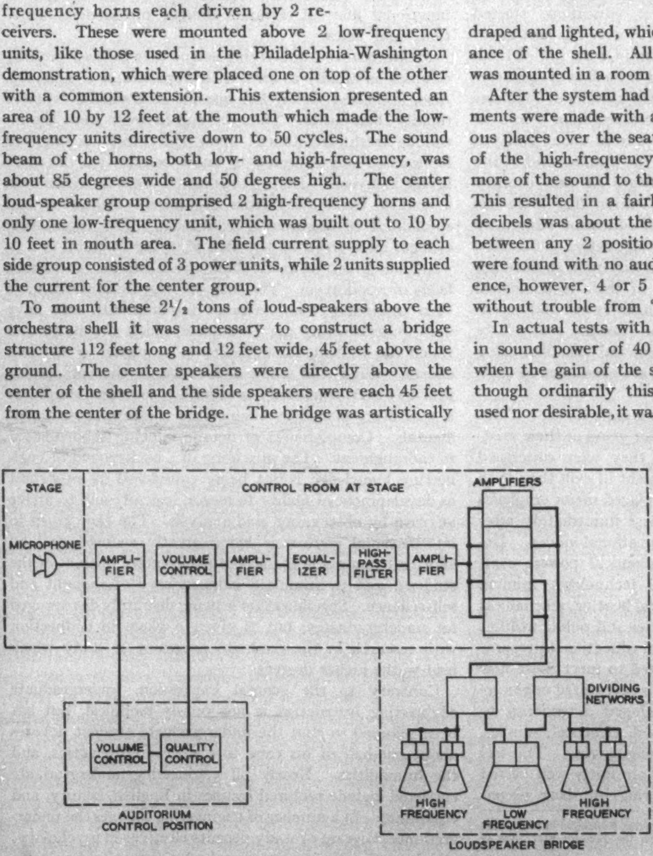
The loud-speaker groups on the sides consisted of 4 multiple-unit high-frequency horns each driven by 2 receivers. These were mounted above 2 low-frequency units, like those used in the Philadelphia-Washington demonstration, which were placed one on top of the other with a common extension. This extension presented an area of 10 by 12 feet at the mouth which made the low-frequency units directive down to 50 cycles. The sound beam of the horns, both low- and high-frequency, was about 85 degrees wide and 50 degrees high. The center loud-speaker group comprised 2 high-frequency horns and only one low-frequency unit, which was built out to 10 by 10 feet in mouth area. The field current supply to each side group consisted of 3 power units, while 2 units supplied the current for the center group.

To mount these $2^{1}/_{2}$ tons of loud-speakers above the orchestra shell it was necessary to construct a bridge structure 112 feet long and 12 feet wide, 45 feet above the ground. The center speakers were directly above the center of the shell and the side speakers were each 45 feet from the center of the bridge. The bridge was artistically draped and lighted, which added not a little to the appearance of the shell. All amplifier and circuit equipment was mounted in a room at the stage.

After the system had been installed, acoustical measurements were made with a high-speed level recorder at various places over the seating area and the horizontal angle of the high-frequency horns was adjusted to direct more of the sound to the back seats than to those in front. This resulted in a fairly even distribution of sound; 10 decibels was about the greatest difference in sound level between any 2 positions. The maximum gain settings were found with no audience in the bowl. With an audience, however, 4 or 5 decibels more gain could be used without trouble from "singing."

In actual tests with the orchestra present an increase in sound power of 40 times (16 decibels) was obtained when the gain of the system was set at maximum. Although ordinarily this much amplification was neither used nor desirable, it was available to accentuate crescendos. Even in the first row of seats where the sound of the orchestra itself arrived a fraction of a second before that from the loud-speakers, the illusion that all the sound was coming from the performers was still strong. At the rear of the bowl, $^{1}/_{10}$ mile from the stage, the music level was at full volume; and for the first time vocal soloists could be heard satisfactorily.

This demonstration was a good illustration of how telephonic research can help to expand the horizon of music. The multi-channel reproducing system described here gives to an orchestra a covering power previously unattainable and makes possible fortissimo effects that could not be duplicated by the simultaneous efforts of hundreds of musicians.



A typical "stereophonic" channel, 3 like this were used in the Hollywood demonstration

Engineering and Engineering Education

By A. A. POTTER
President, American Engineering Council

Because it is considered to be timely, informative, and lucid, this article is republished[*] here so that the many members of the Institute who are interested in, but not intimately associated with, the field of engineering education may have the benefit of a reflection of current practices and trends in engineering education as seen by a recognized authority in that field.

ENGINEERING strives to provide better and easier ways of satisfying human needs. The astounding improvements which the past 50 years have brought about in our standards of living have gone on simultaneously with a more general appreciation of engineering education. This type of education, started in this country about 110 years ago, received its first impetus by the passage of the Morril Land-Grant Act of 1862, which provided means for the rapid extension of engineering education. From 1862 to 1934 the number of engineering colleges in this country has increased from 6 to over 150, and the engineering enrollment from about 1,000 to over 50,000. The rapid growth in the number and in the enrollment of the engineering colleges of this country during the past 70 years is an indication that there has been public approval of the type of education offered by these institutions. To an increasing extent industries, utilities, and public works are dependent upon engineering college graduates for the solution of their technological problems as well as those of an administrative and executive character. It is significant, for example, that nearly all of the major executives of electrical manufacturing industries and of electrical utilities are graduates of engineering colleges.

Engineering of a century ago was mainly an art. Thus, engineering colleges during the earlier years of their existence stressed manual dexterity; they were concerned more with training for the acquirement of skill than with education in basic principles; they placed major emphasis upon studies which led to usefulness immediately after graduation and not upon general educational values. Developments in transportation, mechanical power, communication, illumination, chemical technology, mining, metallurgy, manufactured gas, central heating, mechanical refrigeration, and other new industries and public utilities have resulted in a demand for special educational preparation. Engineering colleges attempted to meet these new requirements by setting up numerous specialized engineering curricula. In fact, there developed a tendency to magnify the differences between civil, electrical, mining, mechanical, and other branches of engineering. This has resulted in training specialists who are fairly well versed in one narrow branch of engineering but lack preparation in basic theory and an appreciation of the work of other engineers. Actually the work of the engineer in practice has not followed these branches of specialization set up by engineering colleges and the engineering societies, but has been organized largely along the functional lines of research, design, production, operation, and sales.

Meanwhile the underlying sciences have been growing complex as rapidly as have their applications to industry. Also, organized society has become diversified even more rapidly than either. Thus the gap between what the incoming freshman student knew and what the engineer in practice was expected to know became too broad to bridge in 4 years. During the past 30 years there has been a definite trend away from the purely utilitarian and specialized in engineering education. The engineering colleges have given up the idea of trying to train, in a 4-year undergraduate curriculum, specialists for the various fields of application. The best of these institutions have been tightening their entrance requirements, and have been concentrating upon subjects which are basic and which the student has difficulty in acquiring by his own efforts. While the scope and range of the engineering field has been constantly broadening, increased emphasis is now being placed by engineering teachers upon fundamentals. Completeness of details is being subordinated to thoroughness. The providing of a background of engineering knowledge is not being considered as important as development of ability to reason logically and to arrive at truth by observation and analysis. The time given to informational courses is being greatly reduced and an effort is being made to awaken the creative instinct of the student, and to stimulate independence of thought and self-reliance. Specialization is being definitely discouraged for undergraduates, but is given a place in connection with research in the graduate programs of study which lead to the higher degrees.

Contrary to the general impression, undergraduate engineering instruction is not purely technical, but has been planned so that the undergraduate student devotes about one-half of his time to science, mathematics, and the humanities. Nearly all engineering undergraduate curricula include required courses in English, history, and economics. In a number of engineering colleges the undergraduate program of study permits electives in psychology, sociology, accounting, personnel administration, businesss law, banking, corporation finance, and other courses which are helpful to the student in acquiring an understanding of social and economic problems. To an increasing extent, engineering students are receiving instruction in industrial engineering and management. It is the general opinion, however, that extended business training should not take the place, in an engineering curriculum, of basic instruction in science and technology.

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[*] Full text of an article "Engineering and Engineering Education in the United States" republished with special permission from the January 1937 issue of "The Bent" of Tau Beta Pi.

Doctor A. A. Potter is dean of engineering, Purdue University, Lafayette, Ind.; also, president of the American Engineering Council, past-president of The American Society of Mechanical Engineers, and past-president of the Society for the Promotion of Engineering Education.

The growth of junior colleges and of lower and upper divisions in universities has brought to the front the relative advantages of the unified program in which the scientific, technological, and humanitarian studies form an orderly whole in an engineering curriculum, as contrasted with the divided process having two years of a general college or pre-engineering curriculum and a subsequent purely technical curriculum corresponding to the practice of law, medicine, and dentistry. The conclusions of the exhaustive survey made under the direction of the Society for the Promotion of Engineering Education during 1922–1929 favor the 4-year unified engineering college undergraduate curriculum with unity of supervision rather than the divided program under separate administration.

While the soundness of the unified 4-year engineering undergraduate curriculum cannot be questioned, concentration on collegiate forms of education seems to have resulted in the neglect of other forms of technical education. There are no doubt too many institutions in this country offering engineering instruction of collegiate grade. Adequate training facilities for trades and crafts are also available. However, there is a need for specialized technical training which can best be given in a post-secondary type of school, recently designated as a "technical institute." This type of institution is similar to the technical middle schools of Continental Europe and trains for callings and functions between the skilled crafts and the scientific professions. Industry apparently needs for every engineering college graduate 3 people trained in this type of post-secondary school, where the instruction is more intensive and more specialized, and the program of study is shorter than that of colleges.

Until very recently, the interest of engineering colleges has centered in undergraduate instruction, as industry and the engineering profession have given inadequate recognition to resident graduate study. However, during the past decade graduate study or some other form of advanced study has become a necessity for the higher technological posts of industry. In several cases industries have perfected special arrangements with the educational institutions of their localities so that the engineering college graduate may complete requirements for higher degrees by pursuing advanced study while he is gaining industrial experience. Growth in graduate study has been particularly noticeable since 1930, as many of the unemployed have been striving to improve their education. Graduate study is now receiving definite encouragement at a number of engineering colleges as the preparation of their staffs has improved and as better research facilities have become available for the solution of new and advanced problems.

Doctor William E. Wickenden, in his final report as director of the survey of engineering education by the SPEE, made the following pertinent statement about post-scholastic study:

> The most serious deficiency in engineering education is not so much in matter taught or omitted in college, as in allowing the orderly process of education to stop, where it often does, at graduation. To require all engineering students to remain 5 or 6 years in college would be an arbitrary solution, but an artificially simple one.—It seems that the most urgent educational task now before the engineering profession is to create and direct an effective program of continuation education for the first 5 years after graduation from college.

The engineering profession has, in the past, taken little active interest in shaping or in directing engineering education. What aid has been given to engineering education by engineers has been largely individual and unofficial and has not represented the concentrated thought or the united action of the engineering profession. It is, therefore, gratifying that the recently formed Engineers' Council for Professional Development, representing as it does the leading engineering societies, has its program focused upon the educational preparation of the engineer. This council has set as one of its main objectives definite encouragement for the further personal and professional development of the college graduate as a qualifying standard for certification into the engineering profession.

In planning for the future of engineering education it may be desirable to give consideration to the following matters:

The undergraduate engineering college curriculum, concentrated on the underlying fundamentals, should become an accepted form of modern collegiate education, as it acquaints the student with the processes, devices, and methods which make our civilization distinctive. Cultured people are those who understand their environment—the world in which they live—and no type of education so directly assists the individual to understand his present surroundings as engineering education. Some of the graduates of engineering college should be encouraged to continue their preparation for engineering as a career, but a much larger number should be assisted in qualifying to enter the other professions, business and public service.

Considerable pressure is being brought to bear upon engineering colleges to increase emphasis upon business procedure and industrial management. Doctor R. E. Doherty, president of the Carnegie Institute of Technology, is of the opinion that in our enthusiasm to train leaders for industry we must not forget to provide an educational preparation and a promising outlook for technical engineering leadership. President Doherty's warning is timely. Technical engineering leadership and scientific positions must be made worthy and promising on their own score and not merely as a stepping stone for executive and administrative positions. Furthermore, the requirements for a successful executive are a broad range of knowledge and a disciplined mind to attack new problems. All that the engineering college can hope to do is to lay a foundation upon which the graduate may build in preparation for technical or executive responsibilities. Patrick Henry has well stated: "I know of no way to judge the future but by the past." It is only by giving our students a broad foundation that we can properly prepare them to cope with the changing conditions of our times.

Greater attention must be given to economic and historic studies so that the engineer will have a better appreciation of the co-ordination of technology and economics as well as of the science of government which controls his affairs. During the past year several engineering colleges have announced special curricula as preparation for public service. The functions of government are becoming more and more technological in character, and to an increasing extent the engineer's activities are concerned with public works. It is therefore becoming more desirable that all engineers have a better appreciation of the relation of engineering to the public and to its agent—the government. All intelligent people must take an active interest in public questions, as only under a stable government can one make the best use of his talents.

It may be well to give greater attention to studies which will prove helpful in acquainting the student with industrial working conditions, tendencies in industrial organization and legislation, and other matters which may enable him to appreciate the human problems he will encounter. The engineer must know the human element if he is to utilize most effectively the work he designs or builds.

The engineer of tomorrow must have a thorough scientific preparation if he is to make full use of the foundations laid by science. Science and technology are interdependent, and the future progress of one depends upon the other. There is a trend toward more thorough instruction in science and mathematics, and for the general broadening of basic theory in engineering instruction. Quality rather than quantity is the guide in revising programs of study, as the superficial familiarity with many subjects is less valuable than the complete mastery of a few.

College graduates are found to have difficulty in recognizing and in appreciating true values. A better coordination of the educational and social activities of the undergraduate may prove helpful. More of the engineering undergraduate studies should be administered by socially minded professors. A more accurate appraisal of college student activities may also prove desirable. In a number of industries, art and beauty have recently changed deficits into profits. American industry has become aware of the remarkable potency of beauty. Art as a living thing will have to be appreciated by the engineer of the future.

Engineering colleges will do well to devote more attention to the development of desirable personality traits in their students, such as a good address, an agreeable manner, a cheerful attitude, a co-operative ability, a pleasing disposition, and similar traits which are helpful to the professional man in taking his place in society.

A most important objective of all education is the development, on the part of youth, of worthy ideals of character and conduct. The stability of society and the basis for authority in a democratic government depend upon the character and ethical standards of people. It is the duty of all types of schools, colleges, and universities to inculcate high ethical standards, and particularly during the adolescent period of youth when one is highly susceptible to the call of high purpose and refined ideals.

There is always a demand for people of initiative who have the power to think independently and constructively. We are living in an age which places a premium on initiative, the power to take the lead, to plan, to originate. To develop such traits, students must be encouraged to take new paths, to try new experiments, to look into the unknown. To develop the creative leaders of the future, our college students must have opportunities to come in contact with teachers who are in search of nature's truths. Engineering progress is dependent upon research, and new knowledge is absolutely essential for the advancement of engineering education. Furthermore, effective graduate instruction must be accompanied by active research interest on the part of the staff. Engineering is a profession of progress, and the future advances in applied as well as in pure science will depend upon coordinated and organized research. During recent years research problems of great magnitude have been successfully solved by engineering colleges as a result of cooperative relations with industry. Engineering societies, trade associations, industries (both large and small), and public utilities have found that money invested in research at carefully selected engineering colleges paid big dividends, not only in practical results secured but also in increasing the supply of engineers who have the preparation to extend the frontiers of useful knowledge. The best engineering colleges are not satisfied with teaching and the conservation of knowledge as their only function. They realize that efficient technological instruction must find expression in the application of research. Such institutions are always ready to encourage their staffs and their students to extend the boundaries of engineering and other scientific knowledge. American industry has an opportunity to aid in improving the preparation of engineers and scientists by stimulating research in pure and applied science at technological institutions. Such support will result in advancing basic knowledge in science and engineering, will increase the supply of well trained personnel for the research laboratories of industry, and will insure a greater number of people who have intellectual curiosity and ability to extend the frontiers of knowledge.

Engineering touches the life of every person in an industrial nation, so that the general well-being is vitally dependent upon the education of the engineer. From its origin and nature, the engineering college has in the past fallen short of the prime glory of the so-called classical or liberal arts college, which has been fairly successful in inculcating in the minds of its students a strong sense of personal responsibility to their order, their country, and their civilization. This may be partly responsible for the fact that engineers have been in the past too much concerned with the problems of their specialty, and have given little attention to the wider significance of their work or to their social responsibilities. Engineers are expected to think more, to write more, and to talk more on social, political, and economic problems in order to be able to assist in their solution. The engineer must assume the responsibility of social leadership along with representatives of other major professions, in order to aid in stabilizing our national economy and to insure a truly democratic government.

American engineering colleges have a great responsibility in meeting the demands of the times so that their graduates will be capable as engineers and will also have the well-rounded ethical standards and broad interests valid in any professional group. The engineer of today must have a thorough preparation in science and technology, as well as an appreciation of aesthetic values, economic forces, and social trends. At the same time, he must be interested in government and must be conscious of the fact that the stability of our type of government depends upon citizens—citizens with worthy ideals of character and conduct; citizens who are obedient to law; citizens interested in the common good; citizens tolerant of the lawful rights of others; and citizens who realize the interdependence of human rights and property rights.

Part-Time Courses for Graduate Engineers in Chicago

By H. T. HEALD
Member, The Society for the Promotion of Engineering Education

ENGINEERING educators are familiar with the development of graduate work in engineering during the past 15 years, and know that graduate registrations have greatly increased during this period. The increasing importance of graduate training suggests that in large metropolitan communities opportunities should be provided to enable young engineers to carry on a program of advanced study through part-time classes while regularly employed.

Beginning in 1935 the Western Society of Engineers in Chicago has directed the attention of its education committee to this phase of education. . . the assignment of making a study of the facilities for part-time graduate education for engineers and for developing a plan whereby the Society might encourage this type of work.

The study carried out by this committee disclosed that approximately 8,000 engineers between the ages of 22 and 34 were employed in the Chicago area, and that, while adequate provision for undergraduate training was available in evening classes, very few advanced courses were being offered by Chicago colleges, aside from a limited program begun at Armour Institute of Technology in the spring of 1936. Various engineering societies had from time to time sponsored lecture courses, some of which proved quite successful, but the committee felt that any comprehensive program should be carried out by the regularly established educational institutions. Consequently, the co-operation of the University of Illinois and the Chicago colleges and universities was invited, and a plan developed for a program of courses to begin in the fall of 1936, to be sponsored jointly by the Western Society of Engineers and the educational institutions.

As a result, graduate courses for engineers are now being offered on a part-time basis by the University of Illinois, Armour Institute of Technology, Lewis Institute, and the University of Chicago. Courses for the first semester included one class in continuous frames offered by Professor Hardy Cross, through the extension division of the University of Illinois, at the rooms of the Western Society of Engineers; 9 courses, including Diesel engineering, heat and ventilation, alternating current networks, foundations and soil mechanics, water treatment, fuels and combustion, metallurgical materials of construction, advanced calculus and physics of electron tubes, by Armour Institute of Technology; courses in non-ferrous metallurgy, metallurgical calculations, and differential equations by Lewis Institute; and electrodynamics and X-ray crystal analysis, as well as other advanced work in science, at the University College of the University of Chicago. Approximately 300 students enrolled in the combined group of courses in the fall of 1936, showing that a real demand exists for advanced work of this type.

While it is undoubtedly true that only a portion of the students enrolled are interested in working toward an advanced degree, credits obtained are recognized by the respective institutions, and the program at Armour Institute of Technology permits a properly qualified graduate to earn the master's degree upon the completion of a minimum of 8 courses. Arrangements for transfer of credits between institutions are subject to the regulations of the respective schools.

The Western Society of Engineers, functioning as a correlating agency, has made its library available to all students enrolled in these classes, irrespective of membership, and has issued announcements, covering the entire program, which have been mailed to 9,000 engineering graduates.

During the current year the education committee of

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the Western Society of Engineers, including both educators and engineers, is studying the effectiveness of the program already being offered, and attempting to determine the needs for additional work of this type. To assist in this study the committee plans to collect opinions from employers of engineers, as well as to take a census among a large number of engineering graduates, to determine the general fields of engineering in which there may be a demand for advanced study. This information will enable the colleges to relate their programs closely to the needs of engineers in the Chicago area, and should be of material assistance in planning courses for 1937–38.

Although the general program of graduate work for engineers employed in Chicago is still in a development stage, the response to the first year's work has been particularly encouraging. With proper development in succeeding years this type of work seems destined to become an important service to engineers who desire to secure additional professional training during the early years of their employment.

After Graduation—What Then?

By H. P. HAMMOND
President, The Society for the Promotion of Engineering Education

A PRINCIPLE on which there seems to be universal agreement is that it is not the aim of the undergraduate curriculum to produce "finished" engineers—men capable of engaging in responsible professional practice. It follows, therefore, since the profession is concerned in the eventual development of men capable of such practice, that consideration—very careful consideration—should be given to that phase of engineering education, and of professional development, which follows the stage marked by the award of the bachelor's degree. This seems so obvious as scarcely to need statement, yet it is a matter to which very little constructive effort has been devoted and to which, until now, none has been directed by the profession as a whole.

Some 4-year graduates will and should remain in college for more extended training. At present about one-sixth of those holding the bachelor's degree continue their work for a fifth year and secure the master's degree, and a smaller, but increasing, proportion go on to the doctorate. This is as it should be; the engineering college, while not the only place, is doubtless the best place, generally speaking, in which programs of advanced study and research can be conducted. For the bulk of our graduates, however, the formal part of their engineering education stops at the end of the 4 collegiate years, whether or not this is best is not the question now under consideration; even, however, if the program of collegiate engineering education were extended to 5 years, or to 6, the fundamental question of the post-scholastic engineering education and the professional development of the young engineer would remain, demanding consideration of those interested in the welfare of the profession.

What are the elements of this problem and how may it be approached? It may be worth while to summarize some of them even though they are already well and widely known.

There is, of course, the problem of fitting the man to the job, or the job to the man (happily there are now jobs to which men can be fitted). This phase of the problem is of concern to every administrative and personnel officer. Real progress has been made in connection with it in recent years. A committee of the Society [for the Promotion of Engineering Education] under the chairmanship of Professor Bangs, of Cornell, has as its particular duty continued study of this matter.

There is also the problem of giving the graduate—or the about-to-be graduated student—some comprehensive knowledge of the profession he is about to enter—of its professional organizations, of the opportunities it offers and the responsibilities it involves, and of its ideals and ethical standards. Some progress has been made in connection with this phase of the general problem, but apparently less than its importance deserves. Both the schools and the profession have a direct responsibility in relation to it.

Every graduate who plans to follow engineering practice as a career should affiliate himself with the appropriate national societies and local groups of engineers and thereby identify himself as a member of the profession he is joining. While this may be considered as chiefly the concern of the engineering societies, it is one toward which the engineering schools should feel a sense of responsibility.

Then there is the matter of the continuation of the education of the young engineer, and this is the chief problem to which these remarks are addressed. Heretofore our profession has done, or perhaps it might be fairer to say has been able to do, very little in this connection. In some urban centers an increasing number of graduates are

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availing themselves of opportunities for post-graduate instruction offered in evening hours by colleges of the vicinity. In some industries, but almost exclusively in the largest, training programs are provided which range from regular study of a post-graduate nature to planned sequences of experience in various departments of the company. But on the whole there is little or nothing in our profession that serves the purpose of the period of systematic apprenticeship which the medical graduate experiences during his interneship. Up to the present time no means have been available of assisting or of guiding the graduate who feels the need systematically to continue his education through self-directed study. No greater need or opportunity exists for the engineering profession today than in this respect.

And finally there is the matter of informing the graduate of the requirements and procedures of the registration laws in the several states. The college and the profession jointly have an important responsibility in this connection.

Until the present time the various aspects of the induction of the graduate into his career and of his professional development and advancement have been dealt with only sporadically; the profession as a whole has not united in considering the matter or in providing means for dealing with it. The reason for this has been chiefly that no agency has existed through which a common program of effort could be undertaken. Now, happily, that lack no longer exists. The Engineers' Council for Professional Development, upon which the interest of the colleges has centered recently in connection with the accrediting program, has the broader purpose indicated by its title—*professional development*. Accrediting of schools, though a vital matter, is but one phase of the broader program which the council has undertaken. Matters relating to the personal and professional growth and development of the graduate as an engineer and a citizen are being dealt with by one of the council's committees, that on professional training. It was the inauguration of the program planned by this committee on which Past-President Rees [of SPEE] was actively engaged at the time of his death. O. W. Eshbach [chairman, AIEE committee on education] is now serving as the chairman of this committee, which is continuing the work along the same lines as those originally laid out. The work of this committee is of vital importance to the entire profession. It deserves to be supported and assisted . . . as need and opportunity arise.

English in Engineering Education

By C. W. DUNHAM
Port of New York Authority

A MAN is able to convey his thoughts to another person only as perfectly as his own means of expression and the other's understanding of it will permit. Most people in our country are limited to the use of just one tool for this purpose—the English language. How great a part it plays in our lives! How great, then, should be its development! Yet engineers are notoriously weak in their mastery of it.

In the past we have given much study to the determination of the best curricula for the undergraduate work of our engineering colleges in order to give our young engineers the best possible preparation for their life work. My own contacts with graduates for the past 16 years indicate that the results have been good as far as technical education is concerned. However, young engineers are generally deficient in their ability to express themselves with effectiveness and facility, whether orally or in writing. Those who are really capable in this respect are the exceptions rather than the rule. Yet, unfortunately, many of the impressions which create the "boss's" idea of a man's ability are secured through the latter's use of English. Therefore, it is tremendously important for a young man to be competent in handling this great means of conveying his thoughts and knowledge if he is successfully to hold a position of leadership among other men who are well trained in this respect. The question naturally arises, "What can be done about it when the time and capacity of the students are already strained to the limit?"

Obviously, it is unwise to keep piling course upon course in undergraduate curricula. This should not be necessary in order to attain the desired result. Day after day the students are steeped in the study of mathematics, sciences, and similar subjects, but all these studies are carried on through the medium of the English language. Why then, cannot the development of the use of this medium itself become a well-planned though almost unconscious part of all studies?

Naturally, in this connection, the desired goal is the development of the ability to use the ordinary written and spoken words of everyday life with facility, to write concisely and well, to think straight, and to speak clearly and effectively while on one's feet before people as well

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as in the quiet of one's study. Not only the faculty members but the students themselves should realize the importance of these attainments.

To accomplish this goal the study of English should commence as soon as the student enters college and it should continue until he graduates. The faculty of the English department should teach the theory of writing and effective speaking, but the practice of its teachings should be carried out day after day in the other departments by having the closest kind of co-operation among them all. The English professors in a few hours each week should not be expected to counteract the effect of careless or bad habits formed elsewhere. These other departments should insist that all written examinations, reports, theses, and similar work of the students must be satisfactory in composition as well as in subject matter. Oral interrogations or recitations should be held in order to give valuable practice in quick thinking and extemporaneous speaking. These last will also give the students the incidental benefit of listening to the questions and answers of others.

Of course, such a program will require painstaking work on the part of the teachers. However, the possibilities for real service are too great to be neglected.

The classroom is not the only place where practice in the use of the English language should take place. Competition in public speaking, participation in the work of the college paper, preparation of essays and their presentation at meetings of the student branches of the engineering societies, discussion of such essays, prepared and extemporaneous debates, and similar activities should be a regular part of the college life.

I shall try to illustrate the need of this training and its benefits by giving a few examples from the experiences of engineers whom I know. All are true cases even though the names of the individuals are not disclosed.

A chief engineer wanted someone to study a certain bridge project and to make a report upon his findings. As it happened, the engineer who usually did such work for him was on his vacation, therefore, the problem was assigned to a younger man. The latter made the necessary investigation and estimate, then hastily compiled his report. He delivered it in person to the chief engineer. The latter read it in the presence of the assistant chief engineer and the author. He figuratively tore it to pieces because of its poor form and composition although he did not criticize the correctness of the figures. Obviously, that young engineer suffered much more than injury to his feelings.

In another instance a young designer was asked to help with some specification writing during an emergency. He soon demonstrated such clearness and exactness in writing that he was transferred to this part of the organization, receiving at the same time a substantial raise in salary and an advance in title. Some of his fellows failed to realize that the reason for his promotion was an accomplishment whose value they had overlooked.

The preparation of specifications is a good example of the need for exactness in writing. Repeatedly, trouble develops from their indefiniteness or misinterpretation of them. One case centered upon one short descriptive phrase of four words which the contractor claimed meant something entirely different from the intention of the author. The dispute was finally settled with a loss of about $75,000 to the owner.

In another instance a company wished to carry on a lecture program to advertise its engineering services. One of the concern's lawyers was assigned to the job. After the first attempt he was recalled because he did not have the technical background to answer the questions put to him. An engineer was then sent out to carry on the work. His knowledge was sufficient but his presentation of the subject was so uninteresting that he too was recalled immediately. The program finally had to be finished by a few of the men higher up in the company who took turns at the job. The effect of this affair upon the first 2 men needs no comment.

A different kind of case is that of a company which sent one of its engineers to confer with a customer about difficulties that had arisen between them. The engineer understood the matter well enough, but he could not discuss the details calmly and clearly. He soon became antagonistic in his attitude and failed miserably in his mission. The result was an oral order by the chief engineer stating that this man must never again be permitted to represent the company in such matters. His future progress was wrecked. One might say that this case represents poor character rather than weakness in the use of the English language. However, knowing the individual as I do, I believe that his failure was due largely to inexperience in debate and in controlling his speech under difficult circumstances.

Another case concerned 2 young engineers who were about equal in technical ability. The first seemed to be afraid to express himself and to present his views. When he attempted to do so he was inclined to be hesitant and unconvincing in his speech. The second was unafraid, forceful, yet tactful and clear in his discussions. The result was that the second young man steadily forged ahead of the other. Such things have happened too frequently to be commented upon further.

It seems to me that there are 2 sides to this matter of correct and effective use of English which one should master. The first is the attainment of a good vocabulary and knowledge of what is right and proper composition. The second is the development of courage and ability to get on one's feet, to say something worth while and to say it well. These can be mastered by the students only if they are given long-continued practice in writing and speaking in college until they become so accustomed to expressing themselves properly that eventually they are able to concentrate their minds upon their ideas rather than upon the search for words to express those ideas.

In conclusion, let me urge that proficiency in the use of the English language be given one of the chief places among the goals to be striven for by our engineering students. Let it be attained by the whole-hearted co-operation of the entire faculty of the colleges. Thus will our young engineers go forth to Life possessing one of the great qualifications for success.

Power System Faults to Ground

Part I: Characteristics

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Synopsis

THE RESULTS of an extensive oscillographic study of power-system faults to ground are presented herewith. While this study was made primarily to obtain data useful in inductive co-ordination problems, the results are believed to be of general interest as well. They provide data on such items as frequency of occurrence of ground-current disturbances, their monthly distribution, duration, cause, method of clearance, and wave-trace characteristics. Data on fault resistance are given in part II, a companion paper.

Introduction

In connection with a study of low-frequency residuals and methods for their control, conducted by the Joint Subcommittee on Development and Research of the Edison Electric Institute and the Bell Telephone System with the co-operation of several power companies, numerous oscillographic records of power-system currents and voltages at times of disturbances producing ground current, together with information as to the cause and nature of the disturbances, were obtained. Records were secured from 10 systems which were under observation for periods ranging from approximately 1 to approximately 5 years. These records have been analyzed from various standpoints to provide information as to characteristics of power-system faults and disturbances which involved ground current. Since some disturbances were self-clearing and some were due to reclosures on sustained faults, switching, etc., a somewhat special meaning has been attached herein to the terms "disturbance" and "fault" to facilitate the analysis of the data, namely:

Disturbance. Each individual oscillographic record of abnormal 60-cycle current, irrespective of its cause or duration, represents a disturbance.

Faults. The number of faults was arrived at by eliminating from the total recorded disturbances those having a duration of one cycle or less, and those which the power-system trouble records or the oscillogram characteristics indicated to be recurrences of, or reclosures on the same case of trouble. The word "fault" is therefore used to distinguish the disturbances which were probably associated with initial dielectric failure from the total number of disturbances recorded. The requirement of more than one cycle duration for faults was arbitrarily chosen to eliminate from this classification brief surges, many of which were attributed to switching, paralleling of 2 systems, etc.

The data presented herein apply, with minor exceptions, solely to disturbances producing earth-return current and are not concerned with disturbances resulting from phase-to-phase or 3-phase faults except to the extent that these may develop into ground faults as well.

The information given in this paper may be roughly divided into 3 main classes, relating, respectively, to (1) the monthly and yearly frequency distribution of disturbances and faults, (2) classification of disturbances to determine their cause and nature, this classification being based on power-system trouble reports, and (3) certain characteristics of troubles, such as duration, manner of fault clearance, and number and sequence of phase wires involved, this information being deduced principally from the appearance of the oscillographic records.

Source and Nature of Data

The power companies who participated in the collection of the data and whose co-operation made this study possible were the Appalachian Electric Power Company, Central Illinois Light Company, Central Illinois Public Service Company, Superpower Company of Illinois, Dayton Power and Light Company, Pennsylvania Power and Light Company, Philadelphia Electric Company, Potomac Edison Company, Public Service Electric and Gas Company, Tennessee Electric Power Company, Union Gas and Electric Company, and Wisconsin Public Service Corporation.

The power systems utilized in the study are all located in territory where, according to data of the United States Weather Bureau,[1] the average expectancy of thunderstorm days per year is from 30 to 60. They cover an operating voltage range from 26 to 220 kv; some of them operate with directly grounded neutral and others with neutral grounded through impedance. Certain relevant characteristics, such as system voltage, circuit mileage, method of grounding neutral, and extent and kind of ground wires utilized are listed in table I.

For recording disturbances, automatic oscillographs were used. They were tripped, in most cases, by residual or neutral current and were provided with means for photographing the time of occurrence of each disturbance. Provision was made for recording neutral, residual, or line currents in all cases and for recording positive- and negative-sequence and line-to-ground voltages in some cases. All oscillographic records were correlated as far as was practicable with power-system trouble records.

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[1] For all numbered references, see list at end of paper.

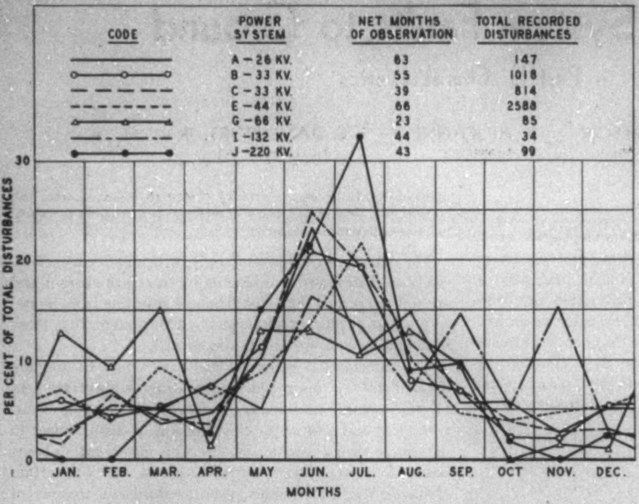


Fig. 1. Monthly distribution of disturbances recorded during entire periods of observation; systems A to J, inclusive, 26 to 220 kv

Frequency Distribution of Disturbances and Faults

Disturbances and Faults per Year per 100 Circuit Miles of Transmission Line

The yearly and, in most cases, the average yearly frequency of occurrence over several years, of disturbances and faults involving ground current are shown in table II for the various systems. This classification was made only for the 7 systems from which suitable data were obtained and only for the calendar years for which the data were practically complete.

The data indicate, in most instances, considerable variation from year to year. The most important cause of this variation is probably the varying severity of lightning storms in different years. This is well illustrated by the fact that weather reports for the city around which system *B* centers show that there were 51 days on which thunderstorms occurred in 1931, compared with 30 in 1930.

Monthly Distribution

The monthly distribution of the disturbances recorded for the entire periods of observations on each of 7 systems are shown in figure 1. Systems *G* and *I* do not show as great a seasonal variation as the other systems, probably because these systems have more effective protection against lightning. System *J*, which operates at the highest voltage, shows a decided seasonal variation, due to the fact that a part of the line mileage is in hilly territory subject to severe electrical storms, and because, at the time of these observations, one section of line did not have effective ground-wire protection.

In figure 2 are shown 3 average curves of monthly distribution of disturbances. The 2 broken-line curves were prepared by averaging the percentages shown in figure 1 for the systems operating at voltages from 26 to 44 kv and 66 to 220 kv, respectively. The solid-line curve is a probability curve, based on the percentage data from all systems.

Table I—Relevant Power-System Characteristics

Power System	Line Voltage Kv	Approximate Circuit Mileage				Neutral Grounds		Ground Wires	Remarks
		Wood Pole	Steel Tower	Cable	Total	Number	Type		
A	26	140		30	170	1	75-ohm resistor	None	Sequential observations on 2 similar networks
B	33	275	125		400	1 1	30-ohm resistor Grounding bank*	Some low conductivity	*Equivalent zero-sequence impedance—540 ohms
C	33	250			250	4	Solid	Some low conductivity	
D	37	64 See remarks					Solid	Some low conductivity	Only one 64-mile wood-pole line under observation
E	44	193	342		535	1	150-ohm resistor	See remarks	72-mile high conductivity; remainder low conductivity or none
F	44	215			215	2–4	Solid		Two grounds at first, others added later
G	66	200	112	1	313	1	30- or 60-ohm resistor	Low conductivity	Switching arrangements permit resistance of 30 or 60 ohms
H	120				434		Solid	Low conductivity	Numerous neutral grounds on this system
I	132		167		167	1 to 4	Solid	High conductivity	Number of grounds gradually increased from 1 to 4
J	220		354		354	4 to 5	Solid	High conductivity except one section for portion of period	System mileage changed from 234 to 354

Correlation Results

Wherever practicable, the oscillograms obtained from each power system were correlated with power-system trouble records. In the case of system *E*, correlation was obtained for oscillograms of voltages induced in an inductively exposed telephone line as well as for the neutral-current records, thus increasing the amount of usable data from this system. The correlation provided information as to one or more of the following items: (1) whether or not a disturbance was noticed on the system at the time an oscillogram was obtained, (2) cause of disturbance, (3) number of phase wires involved, (4) how cleared, i.e., whether self- or circuit-breaker cleared, (5) location of disturbance (line involved and more definite location if known), (6) damage, if any, to the system, (7) any other pertinent information which was available.

Table II—Disturbances and Faults per Calendar Year per 100 Circuit Miles of Transmission Line

(Only Those Producing Ground Current)

	1930			1931			1932			1933			1934			1935			Average	
Power System	Circuit Miles of Line	Disturbances	Faults	Circuit Miles of Line	Disturbances	Faults	Circuit Miles of Line	Disturbances	Faults	Circuit Miles of Line	Disturbances	Faults	Circuit Miles of Line	Disturbances	Faults	Circuit Miles of Line	Disturbances	Faults	Disturbances	Faults
A—26 kv				169	15	12	169	21	16	169	29	21	169	13	10	172	10	8	18	13
B—33 kv	360	36	28	400	64	41	400	55	35										52	35
C—33 kv							250	80	54	250	108	69	250	90	56				93	60
E—44 kv				535	108	45	535	94	48	535	85	36	535	88	46	535	65	30	88	41
G—66 kv				313	13	8													13	8
I—132 kv	167	6	5	167	5	4													6	5
J—220 kv	234	11	10	306	10	9	3	6	6	354	6	6							8	8

In table III is given, where practicable, a classification of all correlated disturbances in accordance with the attributed primary cause of the disturbance and the nature of the trouble experienced on the power system. As mentioned earlier, only disturbances producing ground current, that is, one or 2 line-to-ground or unbalanced 3 phase-to-ground disturbances are included in these data. In order to show exactly what has been included in the various classifications, some of the items are explained in more detail at the end of the table.

In obtaining correlation between the oscillographic records and power-system troubles for system *E*, more attention was paid to the geographical location of the fault and the actual damage to the system than to the primary cause of the disturbance. For every other power system included in this report, the primary cause of the disturbance was given first consideration, but the correlation, especially with regard to lightning as the primary cause, is by no means considered perfect for any system. The correlation is probably the best for systems *A*, *I*, and *J*, but it is thought that the percentage of records directly attributed to lightning is, in all cases, especially system *E*, too small. It is probable that most of the disturbances in items *A*-2 and 3 of table III were also caused by lightning. Consequently the sums of the percentage values of items *A*-1, 2, and 3 of table III are probably more nearly representative of the percentages due to lightning than are values in item *A*-1 alone.

The values given in table III include all correlated disturbances, irrespective of their duration. While correlation of very short duration disturbances usually would not be expected, a number of those of one cycle or less duration were correlated as due to foreign objects in the line and failures at substations. It seems probable that these were mostly disturbances during the preliminary stages of dielectric failures, such as the spitting over of a transformer bushing just prior to breakdown. They were frequently closely followed by long-duration disturbances. For example, several consecutive oscillograms were sometimes obtained showing an occasional half-cycle or cycle of the type illustrated in the central portion of figure 5, followed by an oscillogram of uniform wave shape of the type shown at the bottom of figure 5. (This particular illustration is a reproduction of one

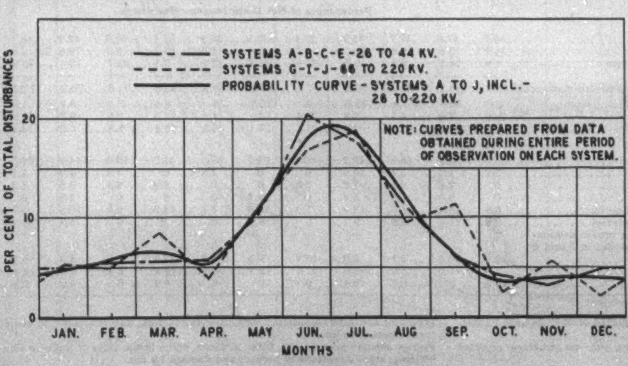


Fig. 2. Average curves for monthly distribution of disturbances

continuous oscillogram, and according to earlier definition, represents one disturbance.)

Fault Characteristics Deduced From Oscillograms

Durations of Disturbances and Faults

This portion of the analysis is intended to give, as nearly as possible, a representative picture of the distribution of disturbances and faults with respect to their durations while involving ground, as determined from oscillographic records of power-system neutral and residual currents. The results for each of 8 power systems are shown graphically by the cumulative percentage curves in figures 3 and 4. The differences between the curves in these 2 figures, for corresponding systems, are due largely to the elimination of disturbances of one cycle or less duration from the curves applying to faults.

Because of the multiple neutral grounding and system layouts, the durations for systems *F* and *H*, obtained by an oscillograph at only one location, were not necessarily the total durations of the troubles. For the other systems included in figures 3 and 4, total durations were shown by the oscillographic records.

Wave-Trace Characteristics

The oscillograms of neutral or circuit-residual current from each of 9 power systems have been classified in accordance with the characteristics shown by their wave traces. Under this classification the oscillograms have been listed as those showing (1) uniform wave, (2) uniformly attenuated wave, and (3) irregular wave. Those having uniform wave traces presumably indicate constant resistance faults and the others variable resistance faults. The results of this study are shown in detail in table IV. Wherever oscillograms showed one cycle or less duration, or could not properly be included under any of the 3 classifications noted above, they have been placed under headings noting these facts.

Table IV—Wave-Trace Characteristics of Disturbances

Power System	Total Records Classified	Classification of Wave Trace, Per Cent: Uniform	Uniformly Attenuated	Irregular	One Cycle or Less Duration	Unable to Classify
A (26 kv)	147	42.9	2.7	34.0	12.9	7.5
B (33 kv)	1,018	51.9	8.7	21.2	9.6	8.6
C (33 kv)	814	40.7	1.8	32.3	19.4	5.8
E (44 kv)	1,962	54.3	3.1	22.7	11.9	8.0
F (44 kv)	100	65.0	1.0	10.0	24.0	0
G (66 kv)	85	58.8	3.5	15.3	20.0	2.4
H (120 kv)	226	71.6	2.7	8.8	16.0	0.9
I (132 kv)	34	76.5	5.9	8.8	5.9	2.9
J (220 kv)	67	71.7	0	9.0	9.0	10.3

Some typical oscillograms illustrating these characteristics are shown in figure 6. In many cases, the basis for this classification was not as clear-cut as might be inferred from these illustrations alone.

Manner of Clearance

The determination of the manner in which a disturbance cleared, i.e., whether breaker-cleared, self-cleared, or involving some combination of these, was based on (1) correlation data and (2) appearance of the oscillogram wave trace. On this basis, the oscillographic records

Table III—Correlated Disturbances Classified as to Primary Cause and Nature of Trouble

Description	Power System: A 26 Kv	B 33 Kv	C 33 Kv	E 44 Kv	F 44 Kv	G 66 Kv	H 120 Kv	I 132 Kv	J 220 Kv	A to F 26–44 Kv	H to J 120–220 Kv
Net disturbances used in the following classifications:	133	746	592	2171	84	84	65	29	110	...	..
1. Per cent on lines	60.1	76.4	80.4	61.2	46.4	60.7	53.8	69.0	61.8	64.9	61.5
2. Per cent at substations	33.1	9.5	11.3	28.9	25.0	15.5	33.9	27.6	15.5	21.6	25.7
3. Per cent—location unknown	6.8	14.1	8.3	9.9	28.6	23.8	12.3	3.4	22.7	13.5	12.8
	Percentages of Net Disturbances—See Above										
A. Classification as to primary cause											
1. Lightning	39.7	47.6	57.7	41.7	27.4	33.3	52.2	31.1	60.9	42.9	48.1
2. Primary cause unknown	38.4	18.6	19.8	21.0	1.2	0	4.6	24.1	8.2	19.8	12.3
3. Cause, location, and type of trouble unknown	6.8	14.1	8.3	9.9	28.6	23.8	12.3	3.4	22.7	13.5	12.8
Sum of above—probably due to lightning in most instances	84.9	80.3	85.8	72.6	57.2	57.1	69.1	58.6	91.8	76.2	73.2
4. Wind, sleet, snow, rain, and flood—no lightning reported	3.0	10.6	7.8	22.0	0	16.7	0	3.4	0.9	8.7	1.4
5. Foreign objects	10.6	7.9	4.5	4.8	21.4	13.1	4.6	27.6	0.9	9.8	11.0
6. Switching	1.5	1.2	1.9	0.6	21.4	13.1	26.3	10.4	6.4	5.3	14.4
B. Classification as to nature of trouble											
1. Flashovers	51.0	58.4	66.8	42.2	52.4	54.7	61.5	48.2	83.6	54.2	64.5
2. Bushing failures	3.7	1.7	3.5	15.4	0	0	1.5	0	1.8	4.9	1.1
3. Equipment failures	0	2.0	4.1	7.8	3.6	0	0	6.9	6.4	3.5	4.4
4. Whipping conductors	0	0.5	3.0	5.6	0	3.6	0	0	0	1.8	0
5. Conductors down—no structures reported down	3.8	14.4	14.6	13.9	7.2	10.8	6.1	13.8	0.9	10.8	6.9
6. Failure of and damage to supporting structures	0.8	11.3	2.8	9.1	0	8.3	0	0	0	4.8	0
7. Foreign objects—exclusive of those causing broken conductors or damaged structures, which are included in 5 and 6 above	9.9	10.5	3.1	5.0	15.4	9.5	4.6	13.8	0.9	8.8	6.4
8. Switching	1.5	1.2	1.9	0.6	21.4	13.1	26.3	10.4	6.4	5.3	14.4
9. Cable failure	29.3	0	0.2	0.4	0	0	0	6.9	0	5.9	2.3

Explanation of items used in classification:

Flashovers—only cases where no damage was reported or only damage to insulators.

Conductors down—phase conductors, ground wires, etc.—no structures reported down.

Equipment failure—transformers, metering equipment, oil circuit breakers, lightning arresters, etc.

Whipping conductors—contacts with other conductors, line structures, or structures adjacent to line.

Foreign objects—wires, ropes, kites, airplane, crane boom, trees or limbs in line, blasting, etc. Accidents to persons and damage by fire.

Switching—includes disturbances due to switching and synchronizing under normal conditions.

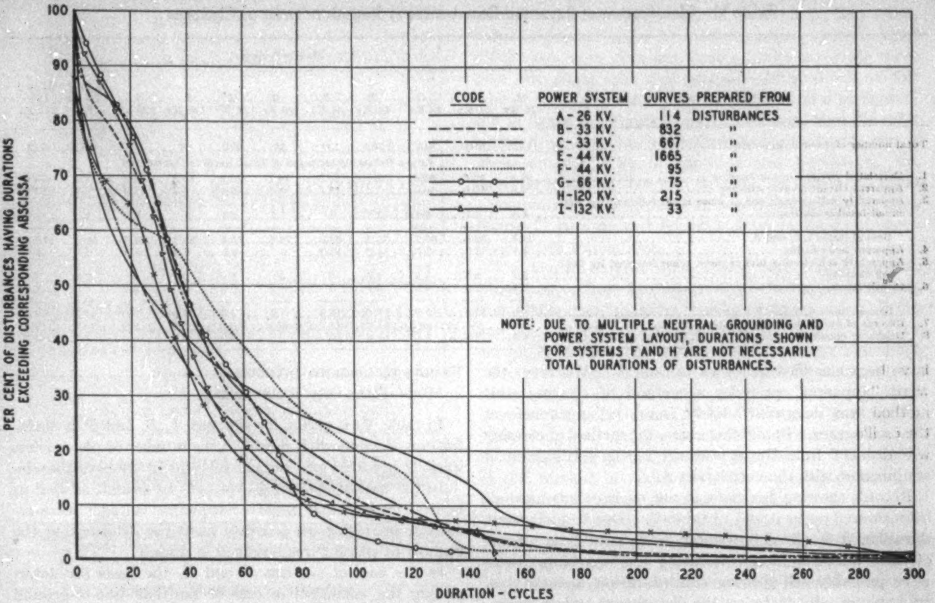


Fig. 3. Cumulative percentage curves of disturbance duration

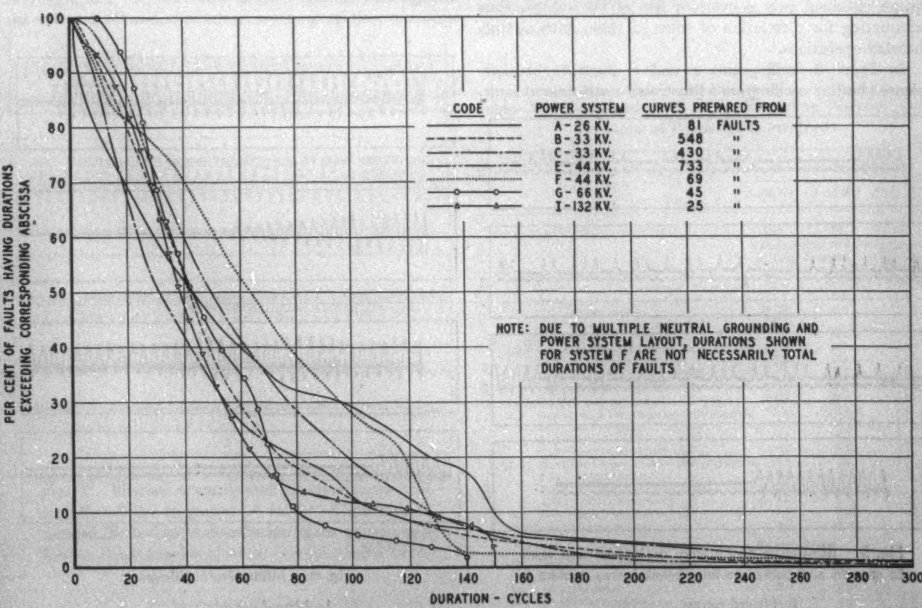


Fig. 4. Cumulative percentage curves of fault duration

Table V—Classification of Recorded Disturbances as Regards Manner of Clearance

	Power Systems										
	A 26 Kv	B 33 Kv	C 33 Kv	E 44 Kv	F 44 Kv	G 66 Kv	H 120 Kv	I 132 Kv	J 220 Kv	A to F 26–44 Kv	H to J 120–220 Kv
Total number of records considered	147	1018	814	1962	100	85	226	34	67	4041	412
	Values Below Percentages of Total Records Considered										
1. Correlated circuit-breaker-clearing	59.8	48.6	46.8	58.8	50.0	74.1	29.2	85.3	61.2	52.4	58.6
2. Apparent circuit-breaker-clearing	4.8	10.9	14.0	4.1	13.0	3.5	45.1	0	11.9	9.7	19.0
3. Apparently self-clearing one or more times followed by final circuit-breaker-clearing	4.8	3.1	4.5	2.7	0	1.2	1.3	0	1.5	3.1	0.9
Sum of items 1, 2, and 3	69.4	62.6	65.3	65.6	63.0	78.8	75.6	85.3	74.6	65.2	78.5
4. Apparent self-clearing	4.1	5.0	3.7	4.3	13.0	0	4.9	5.9	3.0	6.1	4.6
5. Apparently self-clearing one or more times followed by final self-clearing	2.7	5.5	3.5	2.5	0	0	1.8	0	0	2.8	0.6
6. Circuit-breaker operated but fault apparently self-clearing	2.1	8.8	5.0	4.2	0	1.2	0.8	0	3.0	4.0	1.3
Sum of items 4, 5, and 6	8.9	19.3	12.2	11.0	13.0	1.2	7.5	5.9	6.0	12.9	6.5
7. Records of one cycle or less duration	12.9	9.6	19.4	11.9	24.0	20.0	16.0	5.9	9.0	15.6	10.3
8. Unable to classify	8.8	8.5	3.1	11.5	0	0	0.9	2.9	10.4	6.3	4.7

have been classified as shown in table V. Wherever the word "apparent" precedes a method of clearing, this method was determined solely from the appearance of the oscillogram. In all other cases, the method of clearing was deduced from the appearance of the oscillogram in conjunction with the correlation data.

Records showing durations of one cycle or less have all been entered under item 7 of table V. Due to their short duration, it has been impossible to classify them. Some of them were due to synchronizing and switching, others were probably self-clearing short-duration disturbances. Probably in some instances the disturbance had an appreciable duration and for one reason or another the oscillograph obtained only a cycle or less of the record, thus accounting for correlation of some of them with circuit-breaker operations.

In figure 6 oscillograms *a* and *c* illustrate breaker-cleared faults; oscillogram *b* illustrates a self-cleared fault.

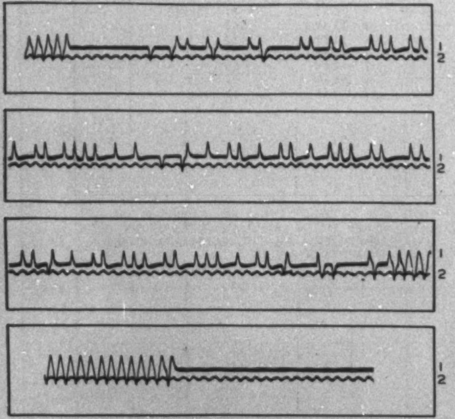


Fig. 5. Illustrative oscillogram of intermittent fault to ground and complete final breakdown, system E

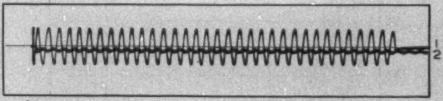
1—Neutral current
2—Negative-sequence voltage

Faults to Ground Involving More Than One Phase Wire

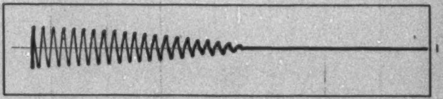
In table VI is given, for systems *A*, *B*, and *E*, a classification of faults with regard to the number of phase wires initially involved and certain subsequent changes therein.

In the case of system *A*, voltages to ground as well as neutral current and negative-sequence voltage[2] were recorded, providing an accurate basis for determining the number of phase wires involved in a fault.

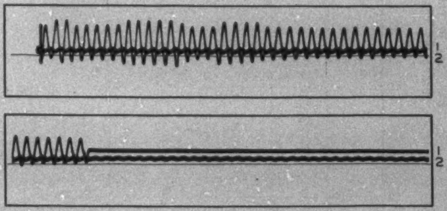
In the case of systems *B* and *E*, the basis for determining the condition of one or multiple line-to-ground faults was largely the appearance of the negative-sequence voltage and neutral current wave traces. The negative-sequence voltage on these systems is low for one-line-to-



(a) UNIFORM WAVE TRACE ; CIRCUIT-BREAKER-CLEARED. SYSTEM B



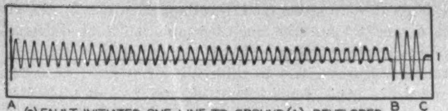
(b) UNIFORMLY ATTENUATED WAVE TRACE ; APPARENT SELF-CLEARED FAULT. SYSTEM B



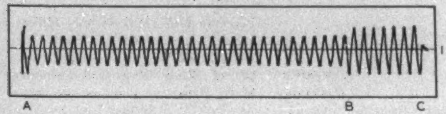
(c) IRREGULAR WAVE TRACE ; CIRCUIT-BREAKER-CLEARED. SYSTEM B

Fig. 6. Illustrative oscillograms

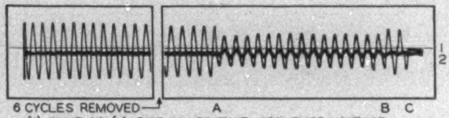
1—Neutral current
2—Negative-sequence current



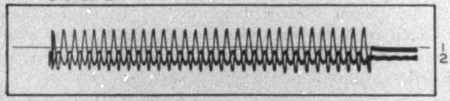
(a) FAULT INITIATED ONE LINE-TO-GROUND (A), DEVELOPED INTO TWO LINE-TO-GROUND (A-B) THEN CLEARED TO ONE LINE-TO-GROUND (B-C). SYSTEM E



(b) SAME AS (a). SYSTEM B



(c) SAME AS (a). RISE IN NEGATIVE-SEQUENCE VOLTAGE INDICATES TWO LINE-TO-GROUND PORTION OF FAULT. SYSTEM B



(d) NEGATIVE-SEQUENCE VOLTAGE INDICATES FAULT INITIATED TWO LINE-TO-GROUND AND REMAINED SO THROUGHOUT. SYSTEM B

Fig. 7. Illustrative oscillograms

1—Neutral current
2—Negative-sequence current

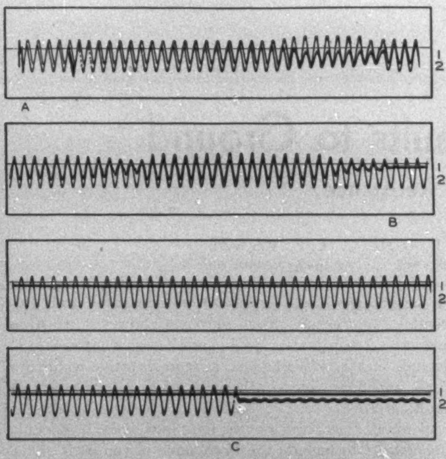


Fig. 8. Illustrative oscillogram of development of fault from 2 line to ground (A to B) to 2 line without ground (B to C); fault self-cleared to ground and finally circuit-breaker-cleared; irregular wave trace; system B

1—Neutral current
2—Negative-sequence voltage

ground faults and high for faults involving 2 phase wires. From inspection it is, in most instances, quite evident which ones were obtained during faults involving more than one phase wire and ground. Illustrations of this type of oscillogram are given in parts *c* and *d* of figure 7 and in figure 8. Figure 7, part *c*, indicates that the fault initiated as one line-to-ground and developed into 2 line-to-ground. The 2 line-to-ground portion of the fault is indicated by the decrease in neutral current accompanied by an increase in negative-sequence voltage. Figure 7, part *d*, and figure 8 show faults involving 2 phase wires throughout.

The neutral-current wave traces, especially in systems where neutral impedance is used, give additional information where ground faults developed from one to 2 line and then back to one line-to-ground. In such cases, an abrupt decrease occurs in the neutral-current magnitude when the second fault develops, followed perhaps by a return to the original value when one of the faults is cleared by breaker operation or otherwise. Oscillograms illustrating the changes in neutral current just referred to are shown in parts *a*, *b*, and *c* of figure 7. The validity of this method of determining the existence of faults to ground involving more than one phase wire has been verified by correlation with power-system operating records in a number of cases. Also the illustration in part *c* of figure 7, in which a negative-sequence voltage wave trace is shown, substantiates the classification of the records shown in parts *a* and *b*, thereof. In determining whether one or more than one point on the system was involved in a fault, the correlation and relay operation data were also utilized.

Table VI—Classification of Faults Regarding Number and Sequence of Phase Wires Involved

	Power System		
	A–26 Kv	B–33 Kv	E–44 Kv
Total number of records considered	105	373	418
	Values Below Are Percentages of Total Records Considered		
1. Initiated 1 line-to-ground	70.5	78.8	87.8
1.1 Remained 1 line-to-ground throughout	52.4	67.5	77.5
1.2 Developed from 1 into 2 line-to-ground	17.1	10.5	7.9
1.21 At one point	11.8	4.0	3.8
1.22 At more than one point	2.9		1.0
1.23 Unable to classify	2.9	6.5	3.1
1.3 Developed from 1 into 3 line-to-ground	1.0	0.8	2.4
1.31 At one point	1.0	0.3	1.0
1.32 At more than one point		0.3	0.2
1.33 Unable to classify		0.3	1.2
2. Initiated 2 line-to-ground	23.8	17.4	6.3
2.1 Remained 2 line-to-ground throughout	10.4	13.4	2.9
2.11 At one point	5.6	6.1	1.2
2.12 At more than one point	2.9	0.3	0.2
2.13 Unable to classify	1.9	7.0	1.5
2.2 Developed from 2 into 3 line-to-ground	12.4	1.9	1.7
2.21 At one point	8.5	1.6	0.5
2.22 At more than one point	2.9		
2.23 Unable to classify	1.0	0.3	1.2
2.3 Developed from 2 into 1 line-to-ground	1.0	2.1	1.7
3. Initiated 3 line-to-ground	5.7	3.8	5.9
Summary of Multiple Line-to-Ground Faults			
1. Total number of records indicating that more than one line and ground were involved	47.6	32.4	22.5
(*a*) At same point	32.4	14.2	7.0
(*b*) At different points	9.5	1.1	2.6
(*c*) Unable to classify	5.7	17.1	12.9

No records which did not of themselves indicate multiple fault conditions were considered as such in this study, even though the correlation data indicated that more than one phase wire may have been in trouble. The reason for this was that the correlation data in many instances were not complete enough to base a classification entirely on them.

No classification of faults not involving ground could be made, since the oscillographs, in most instances, were not arranged to operate unless ground was involved. The classification was not extended beyond the first change in the number of phase wires involved. Thus, if an oscillogram indicated that a disturbance initiated as one line-to-ground and subsequently involved 2 and then 3 phase wires, the classification shows only the initiation of the disturbance and its development from a one line to a 2 line-to-ground fault.

An important reason for making this type of classification was to obtain some indication of the extent of double faults* due to overvoltage. It is felt that the development of a fault from one or 2 phase wires to a greater number of phase wires at more than one point on the power system is more indicative of the effect of overvoltage than is a fault which initiates as multiple line-to ground and remains so throughout, even though more than one point on the power system is involved. In the latter case the faults might well be caused by an electrical storm or storms extending over a large area. The percentage of total faults (and disturbances) which developed from one to multiple line-to-ground faults at different points is given below. This is a summation of the percentage figures given in table VI for items 1.22, 1.32, and 2.22. Also items 1.23, 1.33, and 2.23 of table VI, probably include some cases where the multiple fault developed at different locations.

Power System	Neutral Resistance, Ohms	Percentage of Total Records Indicating the Development of a Fault From 1 or 2 Phase Wires to a Greater Number of Phase Wires and Involving More Than One Point on the Power System
A—26 kv	75	5.8
B—33 kv	30 or 60	0.3
E—44 kv	150	1.2

The authors take this opportunity to thank, in behalf of the Joint Subcommittee on Development and Research of the Edison Electric Institute and Bell Telephone System, all of the companies and individuals therein who co-operated in securing the data on which this paper is based.

References

1. Distribution of Thunderstorms in the United States, William H. Alexander. *Monthly Weather Review*, volume 52, July 1924, page 337.

2. New Sequence System of Polyphase Meters, R. D. Evans. *Electrical World*, volume 81, September 10, 1923, page 333.

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* Two line-to-ground faults in which the fault on one phase wire is at a different point on the system from that on the other phase wire.

Power System Faults to Ground

Part II: Fault Resistance

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Synopsis

AN ALLOWANCE for fault resistance in fault current computations is desirable in certain types of problems. The present paper gives the results of a study made to determine reasonable values of fault resistance to use in computing line-to-ground fault currents, particularly in inductive co-ordination studies. The sources and nature of the data used in the study are described in a companion paper.[1]

Introduction

For many purposes it is sufficient and even desirable. as in the case of certain relaying problems, for example, to assume zero fault impedance in computing fault currents. For certain other purposes, however, such as inductive co-ordination problems, it seems preferable to include in the calculations a representative value for fault impedance or to otherwise allow for its effect on fault currents.

For faults involving ground, fault impedance is generally understood to include the impedance in the path of the fault current between a phase wire at the point of fault and ground, including local ground resistance. Thus

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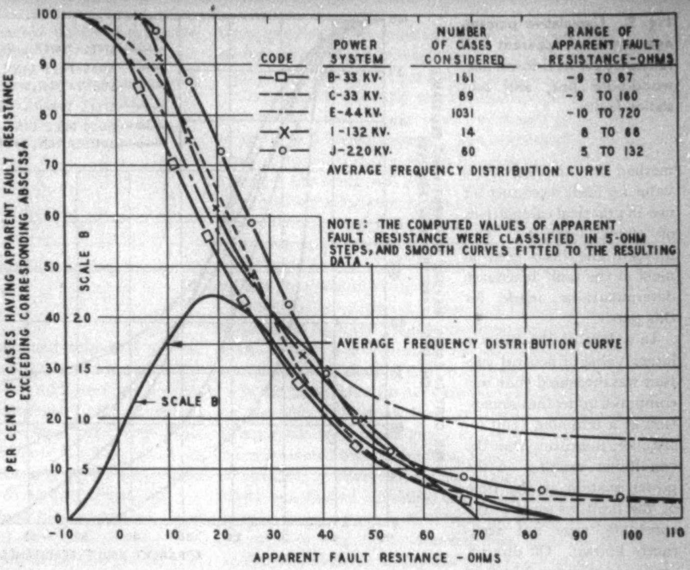
[1] For all numbered references see list at end of paper.

Fig. 1. Cumulative percentage curves and average frequency distribution curve of apparent fault resistances



fault impedance includes the resistance in the arc, in the contact between conductor and ground (in the case of wires falling on the earth), in tower footings, in a foreign object between conductor and tower (or ground) or in some combination of these factors. Fault impedance may be constant throughout the duration of a fault or it may vary continuously, as in the case of an arc which is blown out to gradual extinction by the wind. Fault impedance, in general, appears to be predominantly resistive and in this paper will be treated as though entirely so.

In this paper the approach to the problem of fault resistance is largely statistical and is based on an oscillographic study of power system fault currents, made by the Joint Subcommittee on Development and Research of the Edison Electric Institute and Bell System, in cooperation with a number of power companies. The power systems from which the data were obtained are, in most instances, referred to by a letter, i.e., system *A*, system *B*, etc. Information as to the characteristics of these systems and the nature and extent of the study on which this paper is based is given in a companion paper.[1]

The method of attack on the problem of fault resistance has, in general, been along 3 different lines:

1. Measurements of neutral current, supplemented by calculations, to determine the "apparent fault resistance" for one line-to-ground faults occurring under actual operating conditions.

2. Measurements of phase currents and voltages on a particular line to determine more directly the fault resistance under actual operating conditions.

3. Measurements (staged tests) and calculations of certain of the individual elements entering into or affecting fault resistance.

Determination of Apparent Fault Resistance

Theory and Limitations

For grounded systems, the formula for computing one line-to-ground fault currents by the method of symmetrical components is:

$$I_F = \frac{3E}{Z_1 + Z_2 + Z_0 + 3R_F} \tag{1}$$

where

I_F = fault current
E = normal generated voltage to neutral
Z_1 = positive-sequence impedance of power system
Z_2 = negative-sequence impedance of power system
Z_0 = zero-sequence impedance of power system inclusive of neutral impedance but exclusive of fault resistance and capacitance to ground
R_F = fault resistance (used here in preference to Z_F to simplify explanation)

In case of accidental faults to ground during routine operation, I_F cannot be measured directly, but in its place a measurement of neutral current at one or more points can be obtained. If there is but one neutral ground on the system $I_N = I_F$ (except for charging current); if there is more than one ground the division of the computed value of I_F between the neutrals can be determined. Assuming that values of the sequence impedances of the power system are available or can be computed, that system conditions at the time of fault including fault location are known, and that measured values of one or more neutral currents under fault conditions are available, a value of R_F can be determined which will make the computed value of I_N equal to the measured value of neutral current.

The value of R_F so obtained is of the nature of a "corrective resistance," since it includes in addition to fault resistance, the effects of differences between the actual and assumed constants of the system. Therefore, values of R_F determined in this way are referred to herein as "apparent fault resistances." While this method may not give a true fault resistance, it provides a statistical

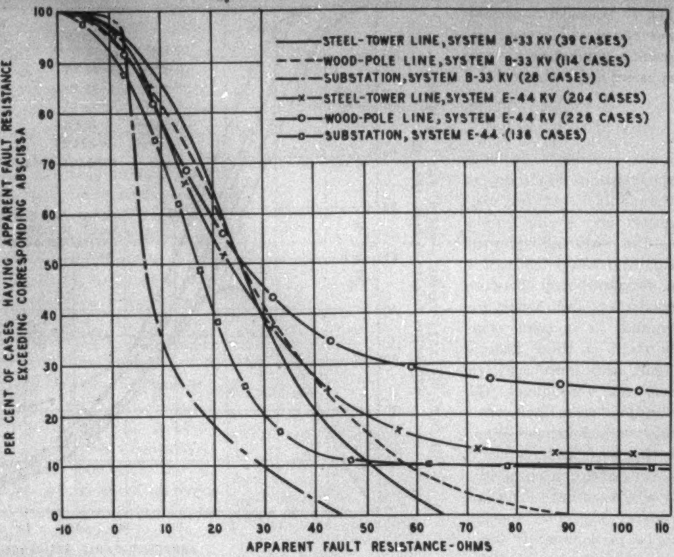


Fig. 2. Cumulative percentage curves of apparent fault resistance for steel-tower line, wood-pole line, and substation faults

method of arriving at a value for fault resistance for use in practical calculations of fault current. This method has been used in most of the fault resistance determinations made for this paper.

In a few of the cases a larger value of neutral current was measured than was computed under the assumption of a zero-ohm fault resistance, indicating that the conditions existing on the power system at the time of the fault, or some of the constants, were not accurately known. On directly grounded systems it will be seen, by reference to equation 1, that the largest fault current magnitude that can be calculated by varying R_F (a real quantity), with other things fixed, is that which corresponds to a negative value of R_F equal in absolute value to one third of the sum of the resistance components of the sequence impedances. Any assumed negative value of R_F larger in absolute magnitude than this would decrease the computed fault current. In the cases used for this paper, one third of the sum of the resistance components of the sequence impedances seldom exceeded 5 ohms for the directly grounded systems. Of course, in cases where a neutral resistance is used, a negative value of R_F much larger in absolute magnitude becomes mathematically possible. Negative values of apparent fault resistance, wherever indicated by the calculations, have been included and given equal weight in the analysis, although it is realized that physically they do not exist. The measured current for 2 cases from system *C*, one case from system *I* and 2 cases from system *J* so greatly exceeded the computed values that no figure for apparent fault resistance could be deduced and these cases were excluded in presenting the results.

RESULTS OF APPARENT FAULT-RESISTANCE DETERMINATIONS

During some 6 years of oscillographic observations on several power systems, a total of 1,375 records were obtained for which the conditions existing on the power system at the time of fault were known with sufficient accuracy to permit computations of apparent fault resistance. The results of these computations for the 5 systems for which the data were sufficient to warrant curves are shown in figure 1.

Since these curves are similar in shape and lie fairly close together, an average cumulative percentage curve was determined from these curves and from it the average frequency distribution curve shown in figure 1 was derived. The abscissa corresponding to the peak of a frequency distribution curve is its mode, or most frequently occurring value. Similar distribution curves were also prepared for the individual systems. The modal, median, and average values of apparent fault resistance applying to the individual systems and the values from the average curve of figure 1 are shown in table I.

Systems *B* and *E* contain a considerable amount of both steel tower and wood pole line construction. The wood pole lines are not generally of the type recently advocated to take advantage of the wood insulation and some of them carry ground wires. The apparent fault resistance data for these systems were classified in accordance with the type of line to which the individual cases applied; also all apparent fault resistances deduced from substation faults were tabulated separately. Figure 2 shows the resultant cumulative percentage curves based on these classifications. For the respective systems, the curves applying to substations are much lower than those applying to lines of either type. While the curves for the steel tower lines on both systems indicate somewhat smaller apparent fault resistances than those for wood pole lines, particularly at the higher values, the modal values for these 2 types of lines are not very different for the respective systems.

Figure 3 shows average curves, based on a classification between apparent fault resistances deduced for faults on lines and at substations for systems for which such classification seemed warranted. Due to the fact that wood

Table I—Modal, Median, and Average Values of Apparent Fault Resistance

System	Number of Cases	Apparent Fault Resistance			
		Range	Mode*	Median**	Average
B— 33 kv	181	−9 to 87	8	22	25
C— 33 kv	89	−9 to 160	24	28	30
E— 44 kv	1,031	−10 to 720	13	23	57
I —132 kv	14	8 to 68	15	28	30
J —220 kv	60	5 to 132	25	31	34
Average curve		−10 to 720	19	25	35

* Value expected to occur most frequently.
** The median of a series of values is the midpoint of the series when arranged in order of magnitude.

pole lines were not of special design and frequently carried ground wires, and also to the relatively small differences between the curves for wood pole and steel tower lines just referred to in the case of systems *B* and *E*, values deduced for faults on all types of lines were lumped together in the average curves of figure 3. They show 18 ohms as the most frequently occurring value of apparent fault resistance for lines, and 5 ohms for substations.

Most of the data on apparent fault resistance were computed from values of neutral current measured 3 or 4 cycles after the fault started, which, in the majority of cases, allowed sufficient time for the disappearance of the unsymmetrical transient, if present. However, fault resistance frequently varied from cycle to cycle and in some cases, particularly on systems operating with neutral resistance, the fault cleared before breaker operation.

Direct Measurement of Fault Resistance

A method of measuring fault resistance during accidental faults on a particular line has been suggested by W. A. Lewis as the result of his studies of distance relaying problems. The method requires the measurement, at each end of the transmission line under study, of the phase currents and the line-to-line or line-to-ground voltages, and the phase relationships among these quantities. From these measurements fault resistance and the location of the fault can be determined by solving, after some rearrangement, equations developed in connection with the theory of determining fault location in distance relaying.[2] In order to obtain measurements of required currents and voltages, at least one 6-element oscillograph is required at each end of the line.

Considerable difficulty was experienced in finding lines suitable and available for fault impedance measurements of the type described above. As a consequence, only one oscillograph installation which would provide data for this phase of the study was made, namely, that on system *D*. The oscillographs were located at each end of a 64-mile line. During the 30 months this system was under observation, 78 records of faults were obtained but only 7 were suitable for fault resistance determinations. The results are given in table II.

From the tabulation it is seen that the fault resistances determined from the 2 equations check reasonably well but that the fault locations are much less reliable, particularly for the higher values of fault resistance.

While these data are not extensive enough to add much to the information on fault resistance, the results are comparable with those given in figure 1. The observations indicated certain practical limitations in this method of measuring fault resistance. One difficulty encountered was that of adjusting the sensitivity of the oscillographs to give proper deflections for faults at any point on such a long line. Another was that of obtaining sufficiently accurate measurements of phase angles from the oscillograms. Also, with the sensitivity required to record fault currents, it was practically impossible to determine the magnitude of the load currents in the non-faulted phases, which may be a source of some error in the calculations.

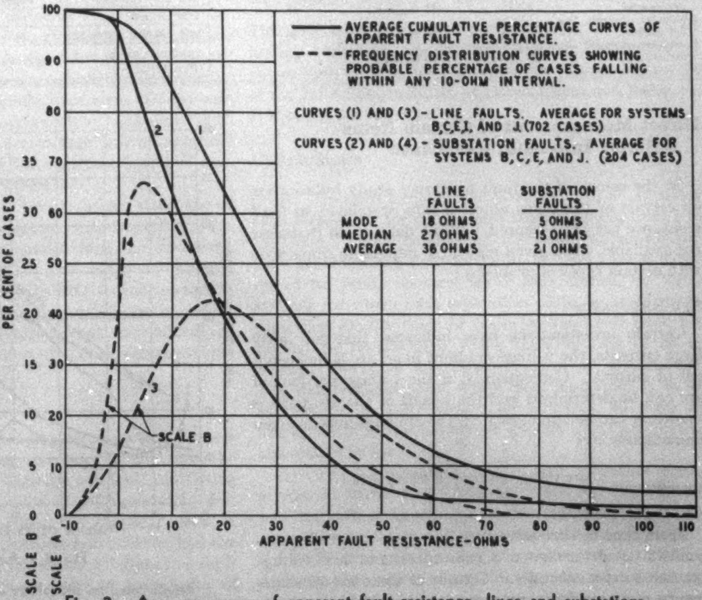


Fig. 3. Average curves of apparent fault resistance; lines and substations

Table II—Fault Resistances Determined by Direct Measurements

Case No.	Computed Fault Location—Miles From Station G (1)*	(2)*	(Avg.)	Fault Resistance—Ohms (1)*	(2)*	(Avg.)
(*a*)	40	25	33	16	12	14
(*b*)	65	22	44	45	45	45
(*c*)	44	43	44	7	7	7
(*d*)	20	22	21	7	22	14
(*e*)**			28	36		
(*f*)**			28	32		30
(*g*)**			28	23		

* These values were obtained from 2 equations, each of which could be resolved into real and imaginary components and solved for fault location and fault resistance and the averages taken. The values under (1) and (2) give the results for the individual solutions.

** Stub-end feed, fault location known. (*f*) and (*g*) are reclosures on fault of case (*e*).

Table III—Miscellaneous Arc and Fault-Impedance Tests

Type of Test	Minimum Length of Arcing Path—Inches	Fault Current—RMS Amps	Computed Fault Resistance—Ohms
(1) From a 132-kv system—tests of 1928			
Arc across insulator	52 (approx.)	359	8.7
Arc across insulator	52 (approx.)	348	9.4
	Length in Contact With Ground—Feet		
Conductor dropped on wet ground	500 (approx.)	356	9.0
Conductor dropped on wet ground	500 (approx.)	365	9.6
Resistances computed from readings taken at sending end of line.			
(2) 33-kv system—tests of 1927			
Conductor dropped on dry ground	5	180 (approx.)	45
Conductor dropped on dry ground	45	200 (approx.)	36
Conductor dropped on dry ground	100	200 (approx.)	33

Direct Measurement of Certain Items Entering Into Fault Resistance

In the course of the fault resistance study information on certain of the items entering into or related to fault resistance has been secured. While data on all items are not available, those given may be of interest in connection with certain types of problems.

Arc Resistance

Certain investigations have indicated that for fairly large currents, the voltage gradient in an arc is independent of current. Consequently, if the voltage per foot of arc can be determined and the length of the arc path is known or can be approximated, the arc resistance is given immediately by:

$$\text{arc resistance} = \frac{\text{arc voltage gradient} \times \text{length of arc}}{\text{fault current}}$$

From time to time advantage has been taken of opportunities to determine arc resistances and arc voltage gradients experimentally. Certain of these arc measurements, of an incidental nature, were not suitable for determining voltage per foot of arc, as no special means of determining arc length were used. The conditions under which certain of these incidental tests were made and the over-all arc resistances measured at various stages of the arc are shown in figure 4. Some additional data on arc resistance and of the arc and contact resistance of a conductor dropped on the ground are given in table III.

Some arc resistance data were also derived from a series of relay tests made on system *J*. The faults were initiated by pulling a string, saturated with a salt solution, across the arcing rings of an insulator string. The approximate lengths of the arcs were determined from moving pictures taken with one camera. The voltage gradient derived from the measurements is shown in figure 5 by the small squares in the range between 2,000 and 3,000 amperes. An average arc voltage gradient of 360 peak volts per foot was deduced from these tests.

A more detailed study of the characteristics of arcs was made in another set of tests in which representatives of the joint subcommitee participated, the results of which have been given in an AIEE paper.[3] In those tests, arc length was determined from moving pictures of the arc taken with 2 cameras set at right angles to each other. It was found that for arc currents between 100 and 800 amperes peak, 67 per cent of the measurements of arc voltage fell

	CURVE NUMBER		
	1 2 & 3	4 & 5	6
NATURE OF TEST	ARC ACROSS INSULATOR STRING	ARC BETWEEN CONDUCTORS	ARC ACROSS PIN INSULATOR
ARC STARTED BY:	FUSE	FUSE	FUSE
SYSTEM KV:	110	33	33
MIN. ARCING DISTANCE	74"	36"	10"
CURRENT RANGE (PEAK ÷ $\sqrt{2}$)	300-440	40-150	390-450

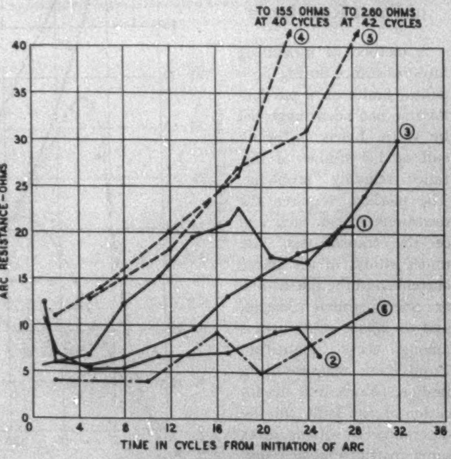


Fig. 4. Arc resistance

Results based on arc-voltage and fault-current measurements during staged tests on transmission lines

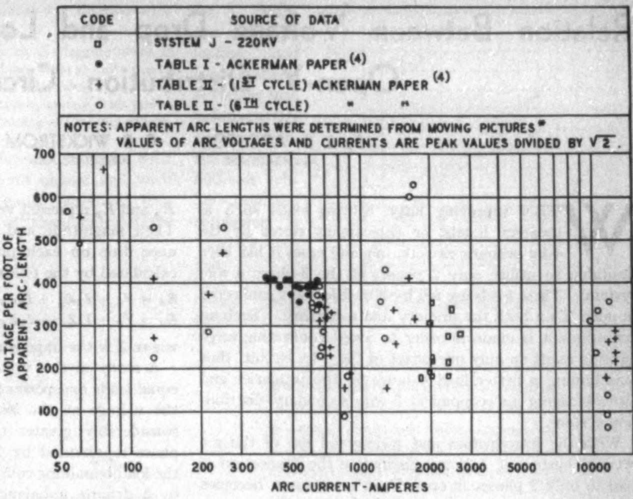
Fig. 5. Volts per foot of arc versus arc amperes

*Total initial arc voltage across pin type insulators for currents ranging from 70 to 10,000 amperes as given in Ackerman's paper were:

2.2-kv pin insulator—250 root-mean-square volts

27-kv pin insulator—500 root-mean-square volts

60-kv pin insulator—900 root-mean-square volts



within ±20 per cent of 300 peak volts per foot of arc length. Also 53 per cent of the cases were above 300 peak volts per foot and 47 per cent were below this value. Consequently, the average voltage gradient in an arc for currents from 100 to 800 amperes peak is concluded to be about 300 peak volts per foot.

Investigations by Paul Ackerman[4] have given valuable test data regarding the relationship between arc voltage, arc current, and arc length, the latter being determined from moving pictures of the arc (taken in one plane only). Arc lengths determined in this manner are generally greater, particularly in the case of small pin type insulators, than the striking distance across the insulator. Results from these tests, in so far as they relate to the voltage per foot of arc, have been plotted as a function of current in figure 5. On the basis of his tests Ackerman reaches the following conclusion regarding arc voltage: "The arc voltage is thus chiefly dependent on the arc length. . . . For practical purposes it may be assumed that for long stretched arcs, the arc voltage will be approximately 400 root-mean-square volts per foot length of arc, irrespective of short-circuit current."

The data from the various investigations cited above are in reasonably close agreement with regard to the voltage gradient of an arc, considering the necessary approximations in arc length. The range in average value of gradient is from 200 to 400 root-mean-square volts per foot of arc. (While root-mean-square values are quoted, it should be realized that arc current or voltage waves are usually distorted. Peak values divided by $\sqrt{2}$ were used in analyses.)

TOWER FOOTING RESISTANCE

For faults to towers on lines having no ground wires, a single tower or pole footing resistance enters into the fault resistance, and unless data are available on footing resistances, the amount to allow is problematical. For lines provided with ground wires, the shunting effect of the other towers along the line becomes a factor and the importance of tower footing resistance in influencing fault current diminishes. It appears that, in a majority of cases encountered in practice, tower footing resistance on lines having ground wires, may be neglected without introducing appreciable error in fault current calculations if l, the length in miles of the section of line under consideration, is greater than

$$5\left(\frac{\sqrt{\text{average tower footing resistance}}}{\text{number of towers per mile}}\right)$$

This conclusion is based on a study of the effect of tower footing resistance on the zero-sequence impedance of power lines by a method given in an engineering report of the Joint Subcommittee of Development and Research, E.E.I. and Bell System.[6]

Conclusions

(*a*) The most frequently occurring values of "apparent fault resistance" for the systems studied ranged from 5 to 25 ohms. Those determined for faults at substations were generally less than for faults on lines; those determined for faults on steel tower lines tended, for the 2 systems for which such separation could be made, to be somewhat smaller than for faults on wood pole lines, but taking the results as a whole there appears to be no marked difference for these 2 types of construction. The data indicate that, where fault resistance is to be allowed for in fault current computations, 20 ohms for line and 5 ohms for substation ground-faults are reasonable values to use.

(*b*) The direct measurement of fault resistance during accidental faults, while possible, is subject to numerous practical difficulties which make the accumulation of data by this method slow and rather expensive.

(*c*) Fairly comprehensive information on arc resistance indicates that, above about 100 amperes arc current, the

(*Concluded on page 474*)

Relation Between Voltage Drop and Load Balance in an Open-Y Distribution Circuit

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WHEN supplying large lighting loads such as theaters, hotels, or department stores by the 4-kv primary circuits, in many cases it has been desirable to utilize only 2 phases of the 3-phase 4-wire system. These loads are fed by 2 transformers connected in open Y on both the primary and secondary. Such an arrangement is made in order to avoid connecting large lighting loads on only one phase of the 4-kv circuit, thus maintaining a better load balance on the primaries and also obtaining an economical 3-wire secondary distribution system.

With the introduction and widespread use of the a-c network system of Δ-Y transformation the connection of load to only 2 phases in open Y, in some cases, becomes necessary. This is particularly true when the load is cut from d-c to a-c and the old 3-wire system in the building is to be utilized. In both of these methods of distribution the secondary connections are essentially the same and serious voltage-regulation difficulties will arise unless the load is correctly—not generally equally—divided on the 2 phases.

It is a well-known fact that when load is fed from a 3-phase 4-wire system the most desirable arrangement would be to balance the load on the 3 phases. With balanced load, the neutral wire will carry no current and the voltage drop on all 3 phases will be equal. Any unbalancing of the load will cause the neutral wire to carry current with the result that the voltage drops will not be equal on all phases.

In this paper the effect of connecting load to only 2 phases will be considered. In figure 1, V_A and V_B represent the applied voltages for A and B phases, respectively, forming an angle of 120 degrees. Also, I_A and I_B represent the currents for the same phases and lagging their respective voltages. Then I_N will represent the current in the neutral and its value will depend upon the magnitude and direction of I_A and I_B. Its magnitude can be computed by the following formula

$$I_N = \sqrt{I_A^2 + I_B^2 + 2I_A I_B \cos\theta} \qquad (1)$$

where θ is the angle between I_A and I_B.

The impedance drops on A and B phases are represented by V_AE_A and V_BE_B, respectively. Also, the impedance drop on the neutral, causing the neutral point of the system at the load to be shifted to N_1, is represented by NN_1. Then the vectors N_1E_A and N_1E_B or simply E_A and E_B represent vectorially the voltages at the loads. Their magnitude and direction depend upon the impedance drop on each phase and the neutral and can be calculated by the following formulas:

$$E_A = V_A - I_AZ_A - I_NZ_N \qquad (2)$$

$$E_B = V_B - I_BZ_B - I_NZ_N \qquad (3)$$

where Z is the impedance of the conductors.

A study of this vector diagram, which was drawn for equal loads and power factors on both phases, shows that the voltage on the leading phase at the load, N_1E_A is considerably greater than the voltage on the lagging phase represented by N_1E_B. With the power factor of the load remaining constant, the voltages can be equalized by a definite unbalancing of the load on the 2 phases. The voltages can also be equalized by a change in the power factor of the load, as will be illustrated later.

With these fundamental characteristics of an open-Y circuit in mind it will be shown how they can be applied to produce good voltage regulation on wiring in buildings connected to 2 phases of the network system.

A study of various sizes of 600-volt rubber-insulated conductors installed in building conduits was made to determine the voltage drops at various power factors and various load balances. The resistance for these conductors was taken at 50 degrees centigrade and the reactance was calculated for an average position of the conductors in the conduit, using the formula

$$D = 2\left(\frac{S}{2} + \frac{\frac{1}{2}S}{\cos 30°}\right) = 2.153\,S$$

$$\therefore S = 0.465\,D \qquad (4)$$

where D is the inside diameter of the conduit and S the distance between centers of conductors.

Then, $X = 2\pi 60[14.051 \log (S/r) + 1.524]\,10^{-8}$, r being the radius of wire.

It was also assumed that the phase wires and the neutral were of the same size.

The calculated values for the reactance are shown in table I.

With the computed reactances and given resistances of these conductors, as shown in the table, calculations can be made using formulas 2 and 3 determining the voltage drops on the leading and lagging phases for various power factors and various load balances. Such calculations were made for number 4 wire with balanced load on both leading and lagging phases at various power factors, and the results were plotted as shown in figure 2. A study of these curves shows the following facts:

1. With the load remaining constant, an increase in power factor from 0.7 to unity results in an increase of voltage drop on the leading

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phase, whereas on the lagging phase the voltage drop decreases with an increase in power factor.

2. At 0.7 power factor the voltage drop on the lagging phase is more than twice the drop on the leading phase, while at unity power factor the voltage drop on the lagging phase is less than that on the leading phase. It is apparent that at approximately 0.98 power factor the voltage drops are equal on both leading and lagging phases.

Similar computations were made for number 4 wire with constant power factor of 0.9 on both phases and with various load balances on the 2 phases, based on 100-ampere total load. The results of these calculations were plotted as shown on figure 3. It will be noted that for a load balance of 65 per cent on the leading phase and 35 per cent on the lagging phase the voltage drops are 2.65 volts and 1.5 volts, respectively. With a load balance of 65 per cent on the lagging phase and 35 per cent on the leading phase the voltage drops are 3.25 volts and 0.35 volts, respectively. The voltage drops on both phases can be equalized at 2.0 volts as shown by connecting 44 per cent of the load on the lagging phase and 56 per cent of the load on the leading phase.

Of course, unbalancing the load will increase the copper losses in the wiring but this increase has little significance when compared with the improvement in voltage regulation. It can be shown that by unbalancing the load to a point where one phase carried 30 per cent and the other phase 70 per cent of the total load, such as would be the limit of unbalancing in application, the increase in copper losses amounts to 26.6 per cent.

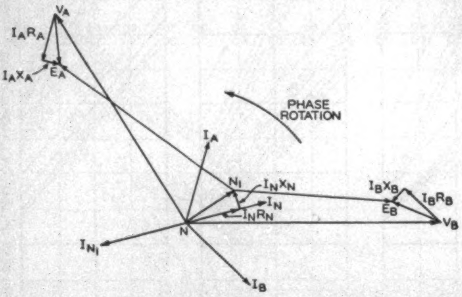


Fig. 1. Vector diagram of an open-Y distribution circuit

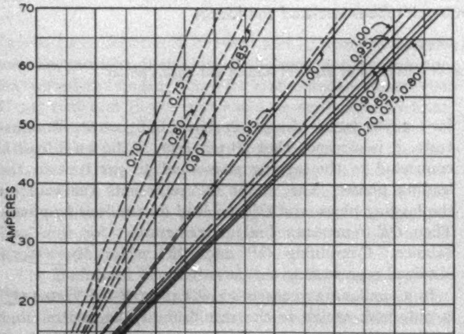


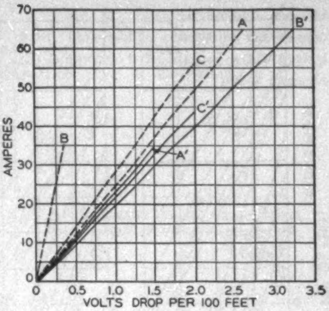
Fig. 2. Voltage drops on leading and lagging phases at various power factors with balanced load and number 4 600-volt rubber-insulated conductors in $1^1/_4$-inch conduit

Numbers on curves are power factors

Solid lines for lagging phase; dashed lines for leading phase

Fig. 3. Voltage drops on leading and lagging phases at various load balances at 0.9 power factor and number 4 600-volt rubber-insulated conductors in $1^1/_4$-inch conduit

Solid lines for lagging phase; dashed lines for leading phase



A—65 per cent of total load on leading phase

A'—35 per cent of total load on lagging phase

B—35 per cent of total load on leading phase

B'—65 per cent of total load on lagging phase

C—56 per cent of total load on leading phase

C'—44 per cent of total load on lagging phase

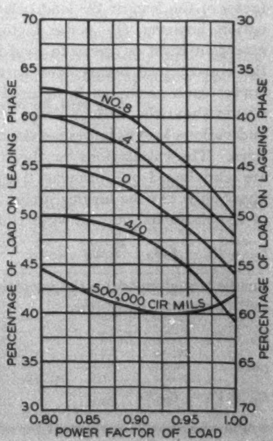


Fig. 4A. Chart showing the proper load division between phases at a given power factor to give the same voltage drop on each phase

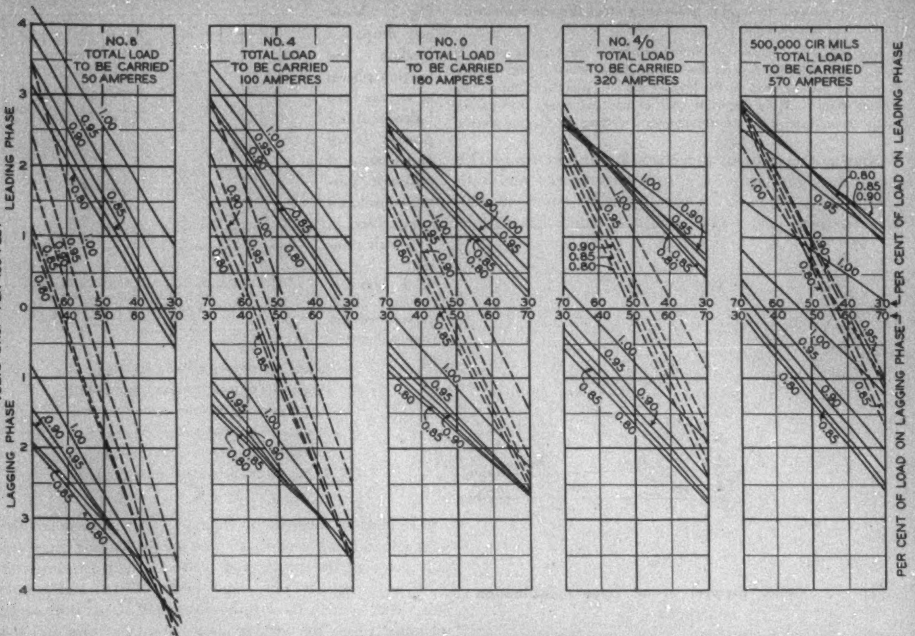


Fig. 4. Relation between voltage drop and load balance for load connected to only 2 phases of 3-phase 4-wire secondary network for various power factors; 600-volt rubber-insulated conductors

Numbers on curves are power factors

Solid lines are voltage drops; dashed lines are differences in voltage drops between leading and lagging phases

It has been shown that the voltage drops on both phases can be equalized by changing either the power factor of the load or the load balance. In practical application, however, the power factor is generally fixed and attention must be given to load balance. To determine the correct load balance for various sizes of conductors curves such as shown in figure 4 can be drawn. These curves show the voltage drops at various power factors and various load balances for the more generally used wire sizes. The calculations for the voltage drops on figure 4 are also based on formulas 2 and 3. Considering one phase only, say the lagging phase, and with the impedance of the phase and neutral wires equal, the formula

$$E_B = V_B - I_B Z_B - I_N Z_N$$

can be transformed by the vectorial addition of the phase and neutral currents into

$$E_B = V_B - (I_B + I_N)Z$$

or

$$E_B = V_B - I_{BN}Z \qquad (5)$$

The graphical representation of this vectorial addition for a power factor of unity is shown in figure 5. To illustrate, it is assumed that 60 per cent of the total load is connected to the lagging phase and 40 per cent to the leading phase. The vector OP represents the load on the lagging phase and OQ the load on the leading phase. Then OR represents the neutral current for this load balance. Combining OP and OR vectorially, OS is obtained representing the current I_{BN} of formula 5.

In a similar way combining OQ and OR the vector OT is obtained, which is the resultant of the neutral and leading phase currents. Resultants of all possible load balances, from one limiting condition where the entire load is connected to the lagging phase, to the other extremity where the entire load is connected to the leading phase, line on lines KU and LM.

Continuing to figure 6, the lines KU and LM are the loci of the resultant of the current components as shown in figure 5 at unity power factor. By allowing the power factor to vary from unity to 0.8 on both phases these 2 lines will revolve about point O of figure 6. The portions of the loci of the resultant currents for the neutral and lagging phase, having practical application, lie within the area bounded by the vertical lines DD_1 and FF_1 indicating

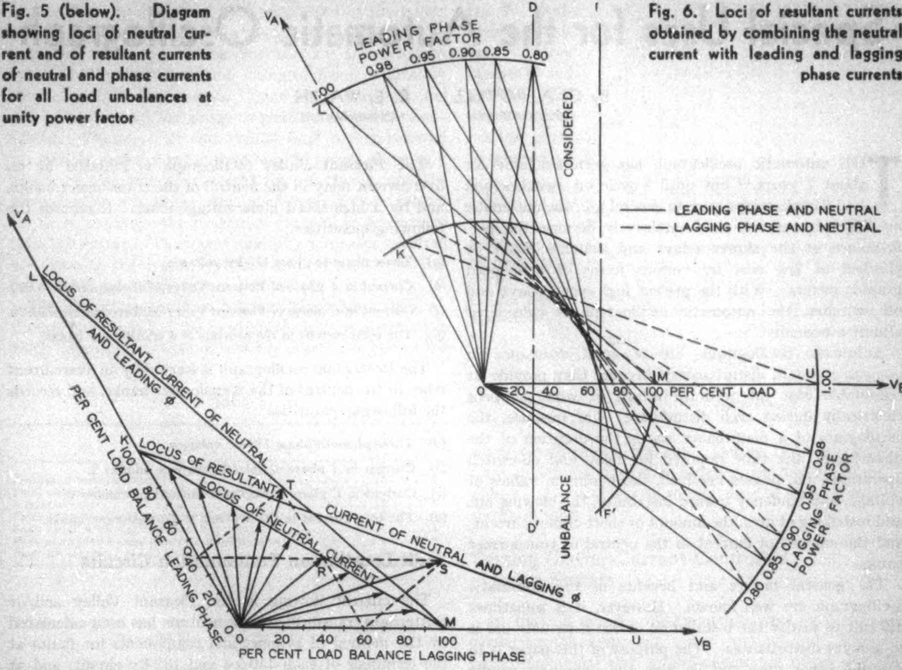

V_A
LEADING PHASE POWER FACTOR
1.00
0.98
0.95
0.90
0.85
0.80
L
D
F
CONSIDERED
LEADING PHASE AND NEUTRAL
LAGGING PHASE AND NEUTRAL
K
0
20
40
60
80
M
100 PER CENT LOAD
U
1.00
V_B
0.98
0.95
0.90
0.85
0.80
LAGGING PHASE POWER FACTOR
UNBALANCE
F'
D'
V_A
L
LOCUS OF RESULTANT CURRENT OF NEUTRAL AND LEADING ϕ
PER CENT LOAD BALANCE LEADING PHASE
K
100
80
60
Q 40
20
0
LOCUS OF RESULTANT CURRENT OF NEUTRAL AND LAGGING ϕ
T
LOCUS OF NEUTRAL CURRENT
R
S
M
U
V_B
0
20
40
60
80
100
PER CENT LOAD BALANCE LAGGING PHASE

Fig. 5 (below). Diagram showing loci of neutral current and of resultant currents of neutral and phase currents for all load unbalances at unity power factor

Fig. 6. Loci of resultant currents obtained by combining the neutral current with leading and lagging phase currents

load balances between 30 per cent and 70 per cent. Similarly the portions of the loci of the resultant currents for the neutral and leading phase for load unbalances between 30 per cent and 70 per cent could be segregated by lines drawn vertically to *OL* with the correct scale.

Multiplication of the resultant currents by the impedances of the conductors would give the impedance drops. Since the impedance of the conductors is a fixed value and the locus of the resultant currents is a straight line, for a given power factor, the locus of the impedance drops would also be a straight line.

The loci of the impedance drops of the various power factors will be related to one another in a manner similar to the relationship which exists between the loci of the resultant currents. From the impedance drops the voltage drops, which are desired in the final analysis, can be obtained by subtracting algebraically the voltage of the load from the applied voltage. Consequently, the loci of the voltage drops at various power factors are straight lines still maintaining the relationship with one another that existed between the loci of the resultant currents in figure 6.

From the preceding analysis the reason for the apparent inconsistency in relationship of the loci of the voltage drops shown in figure 4 is evident. It is also evident that, as the loci of voltage drops are straight lines, the determination of only 2 points on any line is necessary, thus making the drawing of the family of curves a relatively simple matter.

The curves shown in figure 4 are plotted for an unbalance of load between phases from 30 to 70 per cent. Such extreme unbalancing of the load between the 2 phases might not be practicable but it was considered for illustration purposes. As shown by the curves for a number 8 conductor and a power factor of 0.8, with the load divided equally between the leading and lagging phases, the voltage drop for the leading phase per 100

(*Concluded on page 474*)

Table I

Wire Size	Wire Diameter, Inches	Minimum Size Conduit, Inches	Average Spacing, Inches	Reactance per 1,000 Feet	Resistance at 50 Deg. C. per 1,000 Feet
10 solid	0.1019	³/₄	0.348	0.0490	1.117
*8 solid	0.1285	³/₄	0.348	0.0445	.7023
6 solid	0.162	1¹/₄	0.581	0.0510	.4416
4 solid	0.2043	1¹/₄	0.581	0.0456	.2778
2 solid	0.2576	1¹/₂	0.697	0.0446	.1747
0 stranded	0.373	2	0.93	0.0427	.111
0,000 stranded	0.528	2¹/₂	1.16	0.0398	.0558
250,000 cir mils stranded	0.575	2¹/₂	1.16	0.0378	.0478
500,000 cir mils stranded	0.814	3	1.395	0.034	.0237
1,000,000 cir mils stranded	1.152	4	1.86	0.0327	.0118

* The Commonwealth Edison Company permits the installation of 3 number 8 wires in ³/₄-inch conduit.

Special Uses for the Automatic Oscillograph

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THE automatic oscillograph has been available for about 7 years,[1,2] but until 8-cycle oil switches and 1-to-6-cycle relays were in general use, the automatic oscillograph was not used extensively because the performance of the slower relays and switches could be checked at low cost by various forms of high-speed graphic meters. With the present high-speed relays and oil switches, the automatic oscillograph is considered almost a necessity.

Automatic oscillographs are of great assistance in analyzing system disturbances[3,4] because they provide at reasonable cost an accurate record of what happens electrically during each disturbance. For instance, the oscillogram of a disturbance shows the duration of the disturbance, the time required for relay and oil-switch operations, the phases involved, the minimum values of voltage, any tendency toward instability, the blowing out and restriking of arcs, the amount of short-circuit current, and the amount of current in the neutral of transformer banks.

The general nature and benefits of the automatic oscillograph are well known. However, it is sometimes difficult to justify the installation of one if its only use is to analyze disturbances. The purpose of this paper is to describe other uses and to give the operating results which have been obtained.

The 3 special uses described are:

1. Fault location on transmission circuits.
2. Testing carrier-current-controlled relay system.
3. Keeping a check on the operation of the relays controlled by carrier.

The first is applicable to most systems and has been used to some extent, but little has been published on the results obtained.[5] The second is a typical example of the possibility of using the automatic oscillograph for special tests instead of requiring a portable laboratory oscillograph. The third is not applicable to many systems, but it indicates a method of obtaining additional information.

In 1931 an automatic oscillograph was installed at the Rotterdam substation of the New York Power and Light Corporation. Experience with this instrument was so favorable that in 1934 another was installed at the Pleasant Valley substation, for use in connection with the operation of the 132-kv transmission circuits to New York City.

Figure 1 shows the diagram of the transmission circuits centering at Rotterdam and Pleasant Valley.

The Pleasant Valley oscillograph is initiated by an overcurrent relay in the neutral of the transformer banks, and by a high-speed undervoltage relay. It records the following quantities:

(*a*) Three phase-to-phase 110-kv voltages.
(*b*) Current in *A* phase of Pleasant Valley-Millwood number 9,825.
(*c*) Current in *C* phase of Pleasant Valley-Millwood number 9,826.
(*d*) The total current in the neutrals of 4 transformer banks.

The Rotterdam oscillograph is started by an overcurrent relay in the neutral of the transformer banks, and records the following quantities:

(*a*) Three phase-to-phase 110-kv voltages.
(*b*) Current in *A* phase of Spier-Rotterdam number 2.
(*c*) Current in *C* phase of Inghams-Rotterdam number 9.
(*d*) The total current in the neutrals of 2 transformer banks.

Fault Location on Transmission Circuits

The current flowing in the Pleasant Valley and/or Rotterdam transformer bank neutrals has been calculated by the method of symmetrical components for faults at the terminals of each 110-kv and 132-kv circuit, and at several intermediate points along each circuit. These calculations were started in 1932. Curves have been made for each circuit plotting Pleasant Valley or Rotterdam transformer bank neutral current versus tower number. Figure 2 shows these curves for both Pleasant Valley and Rotterdam neutral currents for faults on one of the Rotterdam-Pleasant Valley circuits. For each pair of circuits on the same towers, there are the following curves:

(*a*) Single circuit single-phase-to-ground faults.
(*b*) Double circuit single-phase-to-ground faults.
(*c*) Single circuit 2-phase-to-ground faults.
(*d*) Double circuit 2-phase-to-ground faults.

Since all calculations have been for faults of zero impedance, the actual current in the transformer bank neutrals measured by the automatic oscillographs deviates slightly in some cases from the calculated value. When a fault is found, its location is plotted on the curve sheet to show the relation between actual and calculated tower number. The phase-to-phase voltages shown on the oscillograms have been used on several occasions to calculate the approximate location of 3-phase faults.

As soon as possible after a fault occurs, the films are developed by a member of the substation crew, in dark rooms provided at Pleasant Valley and Rotterdam. The values of the 6 elements shown on the film are carefully

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1. For all numbered references see list at end of paper.

measured at the substation and telephoned to the power control office. Figure 3 is a typical oscillogram. The measured values on the oscillograms are converted to actual system voltages and currents from calibration curves for each oscillograph. From the voltage records on the oscillogram, the phase or phases involved is ascertained. The curve for that type of fault is then referred to, and the tower number determined. Maps showing a profile of the terrain traversed by the circuit, and the tower-footing resistances are studied to see if these factors are likely to change the location of the fault as determined from the curves. The tower number and phases involved are given to the system operator who orders the circuit patrolled 5 miles each side of this tower.

This procedure has been followed since May 1935, although calculation of the location of faults was started in 1932. Previous to 1935, it was the practice to patrol the whole circuit after a trip-out. During 1935 and 1936, a total of 200 man-days were saved in patrols by this procedure. A summary of results for the last 5 years is shown in table I.

Table I

	1932-34	1935	1936
Number of cases calculated	35	25	18
Fault within 10 towers (approx. 1.2 miles) of calculated location	10	14	5
Fault within 2 miles of calculated location	7	3	4
Fault within 4 miles of calculated location	7	3	5
Fault more than 4 miles from calculated location	3	1	0
Fault not located	8	4	4

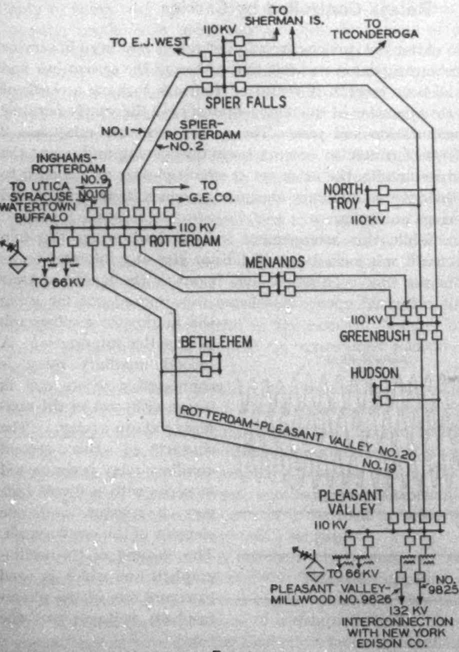
TO SHERMAN IS.
110 KV
TO TICONDEROGA
TO E.J.WEST
SPIER FALLS
NO. 1
SPIER-ROTTERDAM
NO. 2
INGHAMS-ROTTERDAM
NO. 9
NO. 10
TO UTICA
SYRACUSE
WATERTOWN
BUFFALO
TO G.E.CO.
110 KV
ROTTERDAM
TO 66 KV
NORTH TROY
110 KV
MENANDS
110 KV
GREENBUSH
BETHLEHEM
HUDSON
ROTTERDAM-PLEASANT VALLEY NO. 20
NO. 19
PLEASANT VALLEY
110 KV
TO 66 KV
PLEASANT VALLEY-MILLWOOD NO. 9826
NO. 9825
132 KV INTERCONNECTION WITH NEW YORK EDISON CO.

Fig. 1

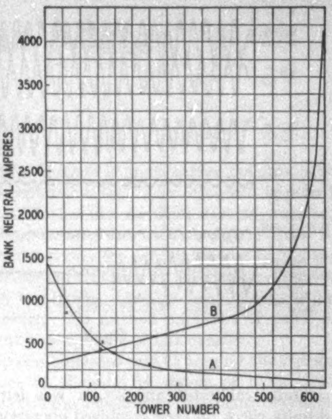

Fig. 2. Rotterdam - Pleasant Valley number 19 and number 20. Single circuit—single phase to ground fault

A—Rotterdam banks neutral current

B—Pleasant Valley banks neutral current

Crosses indicate actual faults

Testing Carrier-Current-Controlled Relay System

In 1933 2 parallel 132-kv circuits were equipped with carrier-current-controlled relay protection.[6] Standard power-directional and ground-directional relays are used for this protection. There are 2 ground-directional relays, one for starting carrier transmission and one with 2 sets of contacts. One set of contacts is for tripping and the other set for preventing the starting of carrier transmission, in case the power-directional relay should operate incorrectly, due to a large amount of through load current at the time of an internal phase-to-ground fault. For phase-to-phase faults a power-directional relay is provided for starting carrier, and in conjunction with an induction-type overcurrent relay, is used for tripping. To increase the sensitivity and the speed of the power-directional relay at the time of a fault, the voltage restraint on this relay is supplied through the normally closed contacts of an instantaneous overcurrent relay.

The relay tripping times with this scheme of protection are approximately 6 cycles. If a fault is external to the section protected, it is necessary for either the power-directional or ground-directional carrier starting relays to operate and start transmission of carrier current, and for the carrier current to operate the receiver relay at the remote end to block tripping, before the tripping relays close their contacts. This means that for correct operation of the protective scheme all of the relays must be closely co-ordinated to be selective within 6 cycles. This selective action is not difficult to obtain if the relays are all properly adjusted as the carrier starting relays open normally closed contacts while the tripping relays are circuit closing. However, after each individual relay was

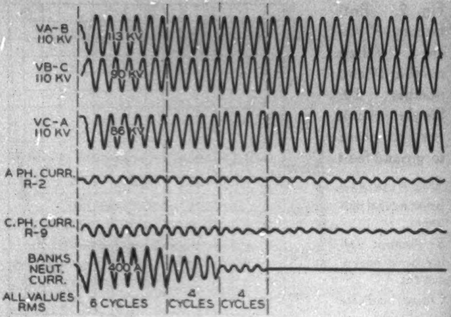

Fig. 3

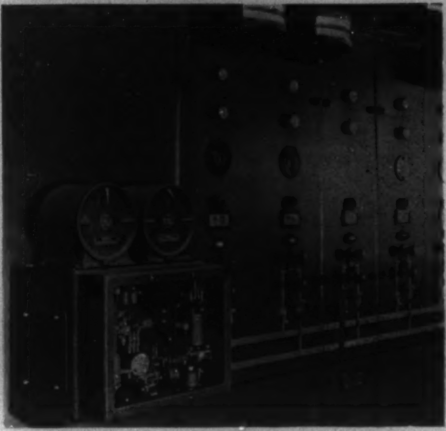

Fig. 5. Automatic oscillograph on switchboard panel in Rotterdam substation

carefully calibrated and set, it was felt there was no definite check on their combined operation as a group or the margin of selectivity between the groups.

In order to obtain this information the automatic oscillograph is used after each periodic calibration and check of the individual relays, to show the operation of each individual relay at that station and their combined operation as a group. One set of tests is made on the ground relays and one on the phase relays. The oscillograph is started by hand and current of proper magnitude and phase angle to simulate faults at various locations is passed through the relays and one element of the oscillograph. The relays actually remove voltage restraint from the power-directional relay, start carrier, operate the carrier receiver relay, open the trip circuit and finally close the trip circuit exactly as in actual operation, except that each set of contacts also energizes or de-energizes (depending on whether it is circuit closing or circuit opening) an element of the oscillograph from a 125-volt d-c source. One element of the oscillograph is energized with 110 volts alternating current, to give a timing wave. As soon as the tripping contacts close, the test current is removed, relays reset, and the oscillograph stopped. This procedure gives a record of the resetting of the relays as well as a record of their operation. A record of the reset is very important as in most cases the margin for insuring correct operation is less during reset than during operation.

Keeping a Check on the Operation of the Relays Controlled by Carrier

After the carrier-current pilot relays had been in service about a year it was felt that although the operations had all been correct, it would be desirable to have a check of the operation of the relays oftener than the yearly periodic calibration and test. The carrier receiving relay has 2 sets of contacts; one set is circuit-opening and opens the trip circuit; the other set is circuit-closing and is used to energize an auxiliary alarm relay which lights a light and rings an alarm.

While this arrangement indicated whenever the trip circuit was locked out, it did not give any information as to the time required to lock it out or the length of time it remained open. A scheme was worked out for using the automatic oscillograph to give this information. A second auxiliary relay is connected with its coil in series with coil of the auxiliary alarm relay. The contact of this second auxiliary relay is connected in series with a 6-volt battery, a resistor, and one element of the oscillograph. The element of the oscillograph is one which is used to record one of the phase-to-phase voltages on the

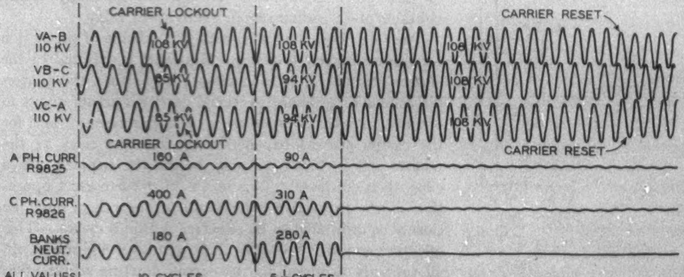

Fig. 4

(*Concluded on page 476–7*)

A New Magnetic Flux Meter

By GEORGE S. SMITH
MEMBER AIEE

Summary

THE MEASUREMENT of magnetic fields in air gaps by the existing methods, is almost as cumbersome as light measurements were before the introduction of the photronic cell or photoelectric tube into that field. This paper describes a meter for the measurement of magnetic flux which seems to parallel the advance made in the lighting field.

About 2 years ago a problem arose in connection with some research work in which continuous measurement of somewhat varying magnetic flux values in air gaps was desired. A survey was made of the methods available, and no method was found suitable for the problem at hand. This problem then became the subject of somewhat extended research, the results of which are given in this paper.

A variety of schemes have been used or suggested for the measurement of air-gap flux, most of which are of value only in some very special type of problem. The 2 most popular methods in use today are first by means of a galvanometer and a search coil and, second, by means of the change in resistance a bismuth wire exhibits when placed in a magnetic field. The first of these methods requires movement of the search coil and an instantaneous reading of the resulting galvanometer deflection. The second requires careful measurement of the resistance offered by the bismuth wire in the field, as well as that in zero field; the percentage change in resistance thus obtained is referred for interpretation to a calibration curve. As is evident, both methods are cumbersome for general use, and require care and skill for accuracy. This is especially the case in the use of bismuth, since a small change in temperature between measurements will often result in a considerable error in the results. Neither of these methods is well adapted to continuous measurements.

After this research problem was well under way the author's attention was called to a publication by F. S. Dellenbaugh, Jr.,[1] describing a miniature d-c generating armature for use in the continuous measurement of magnetic fields, varying or constant. However, this method also has many disadvantages, especially from the standpoint of construction, where it is to be used in fields of very limited area, or in very small air gaps.

The first attempt in this problem was to make an instrument using the Hall effect.[2,3,4,5] This effect appears to be a distortion of the normal current path in a thin flat disk of metal in the presence of a magnetic field. Since various metals have differing Hall-effect factors, this effect seems to depend also upon some property of the material. The Hall effect for bismuth is much higher than for most other metals except tellurium. This approach appeared very hopeful until higher flux densities were approached; then the readings became less, and finally reversed in direction. Figure 1 shows the wiring diagram of the apparatus used and the curves taken for 21 degrees centigrade and 48 degrees centigrade. As has been suggested by Craig[6] and Beekert,[7] this method might be of value in the measurement of low values of flux density.

The next step contemplated was to amplify the change in the resistance of bismuth by means of a vacuum-tube circuit, but this too appeared to offer many obstacles. Finally it appeared possible to obtain the desired results by using a bismuth resistor in each of the 2 diagonally opposite arms of a Wheatstone bridge, as shown in figure 2, and placing both of these in the magnetic field to be measured.

This research has resulted in a very satisfactory method of obtaining a direct and continuous reading of the flux density of magnetic fields, either steady or slowly varying. The same instrument can be calibrated for ranges from full-scale reading of a thousand gausses or less to as high flux densities as may be desired to measure. The calibration curves for 2 ranges on the bridge are shown in figure 3. Figure 4 shows the meter with the bridge removed from its compartment, ready for use.

A study of many of the researches[8] in connection with the behavior of bismuth and other metals in the presence of magnetic fields revealed many points of value. The greatest amount of useful information was furnished by the curves shown in figure 5, plotted from data in the Smithsonian tables. These show the variations to be expected in the use of bismuth at varying temperatures and varying flux densities. Fortunately the variation over the usual working range of temperatures is not very great, so that correction need be made only when more than ordinary accuracy is desired.

Since bismuth is very brittle and is not easily worked, it is usually found pure only in lump or granular form. However, its melting point is rather low (271 degrees centigrade) and it forms well in a cast. Accordingly, it was first cast in a double spiral groove, machined in the face of a brass plate and so arranged that the resulting spiral would be noninductive. A great deal of difficulty was encountered in obtaining any great length with a small cross-section, but after many attempts 2 such spirals were obtained, of about 3.7 ohms each. These were built into a bridge, with very fine copper wire interwound between

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1. For all numbered references see list at end of paper.

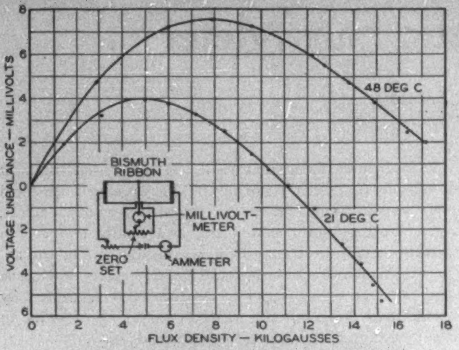


Fig. 1. Voltage unbalance due to Hall effect

the bismuth turns to form the remaining arms. This bridge gave such consistent results in the calibrations and various checks that still better results seemed likely from a bridge with higher resistance in the arms. Hence some bismuth wire was imported from Germany, and a bridge was constructed with 50 centimeters of 0.17-millimeter diameter wire in each spiral. Each arm measured about 28.25 ohms.

In the construction and tests on this bridge, a number of problems arose which were either partially or wholly solved.

First, since bismuth has rather high thermoelectric effect when joined to most other metals, a considerable amount of error might result if the junctions of the various ends of the spirals were not kept at the same temperature. To avoid this the support for the bridge was made of a thin sheet of copper covered on either side with a very thin sheet of mica. To each side of this support were cemented the 3 thin flat copper leads; the spirals and balancing resistors were securely attached to the one end, and a bakelite terminal block to the other. The assembly of bridge and its leads was then covered on each side by a sheet of mica, for protection. The arrangement is clearly shown in figure 6. All junctions were made as near each other as possible so that very little difference in their temperatures could exist. The resulting thickness beyond the terminal block is 1.25 millimeters. No errors from this source have been detected, so that the temperature-equalizing strip may not be necessary.

A second problem arose in the zero shift of the flux meter when the temperature of the bridge was increased or decreased. To overcome this a search was made for some metal having the same temperature coefficient as bismuth, but none could be found. By using a metal of higher temperature coefficient of resistance than bismuth, and using only enough so that its resistance change would always be equal to the corresponding resistance change in the bismuth, the zero shift could actually be made zero. The remainder of the balancing resistance for each arm can be made of manganin resistor which may be placed in the meter case. A portion of one of these should be made variable, in order to correct any possible zero displacements.

The equation used to determine the value of such balancing resistors is as follows:

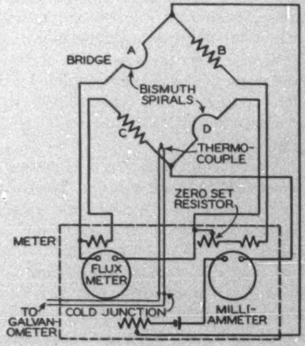
$${}_xR_0 = {}_bR_0\alpha_b/\alpha_x$$

where

${}_xR_0$ = resistance of the balancing resistor at the assumed base temperature
${}_bR_0$ = resistance of the bismuth resistor at the assumed base temperature
α_x = temperature coefficient of the balancing resistor material at the base temperature
α_b = temperature coefficient of bismuth at the base temperature

In this research the final adjustment had to be made by trial. Since some number 40 Brown & Sharpe silk-covered nickel wire was available, it was used for the balancing resistance, though some very fine lead wire would probably be more desirable, since its specific resistance is much higher, it is entirely nonmagnetic, and it would be very easily formed in spirals.

Fig. 2. Wiring diagram for magnetic flux bridge



The several spirals were wound separately, and each was wound noninductive. The 2 spirals of bismuth were placed between those of nickel. With this arrangement quick changes in temperature often result in uneven heating of the various spirals, and thus a temporary shift of the zero. This could be greatly reduced by interwinding the turns of bismuth and its balancing spiral.

Figure 7 shows curves of several of the tests made in studying the zero drift and in correcting it. From the great amount of data taken before the zero drift was corrected the conclusion was evident that this tendency for the zero to shift caused no noticeable error in the measurements, provided the meter was carefully set on zero before the reading, and was checked again after it. The chief difficulty arose when the zero was set in a region of zero field and then the bridge was placed near some metal whose lower or higher temperature would slowly alter the temperature of the bridge.

A third problem presents itself when the temperature of the bridge varies any considerable amount from that at which the bridge is calibrated. A study of the curves in figure 5 will show that when great difference in temperature is involved some corrections must be made, if any great accuracy is desired. In order to determine the variation to be expected in the bridge readings, a small thermocouple was built into the bridge, with the one junction placed between turns, as far into the bismuth spiral as possible. The other junction was carried back into the meter case where a thermometer could be placed in contact with it. The thermocouple was then calibrated for the difference in temperature between these junctions, and it proved to be very sensitive and very accurate. The galvanometer used was external to the meter, though the galvanometer could be built in as an integral part of the meter.

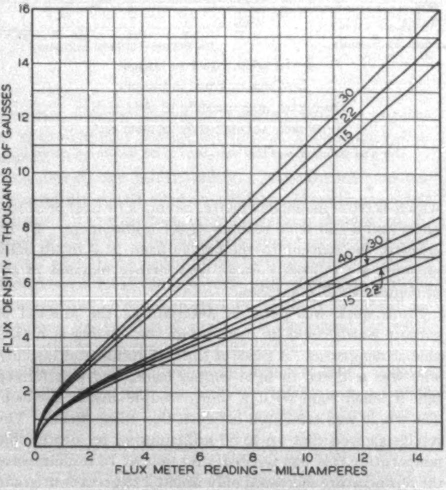


Fig. 3. Calibration of magnetic flux bridge

Using a model 280 Weston 1.5-milliampere d-c meter having 27 ohms resistance as flux meter

Bridge current 21.3 milliamperes for 0–7,500-gauss range; 9.8 milliamperes for 0–15,000-gauss range

Bismuth arms at 23.7 degrees centigrade—28.21 and 28.25 ohms

Nickel arms at 23.7 degrees centigrade—21.80 and 21.78 ohms

Manganin wire in meter case used for remainder of nickel arm balancing resistances

Numbers on curves are temperatures in degrees centigrade

Figure 3 shows such calibrations for several temperatures. The flux meter itself could be calibrated for the usual temperature at which it would be used, say 22 degrees centigrade, and curves could be supplied for enough temperature points above or below so that the reading could easily be interpolated for any temperature within this range.

A mathematical study of the resulting unbalance was made by assuming varying resistance values in the arms and varying currents supplied to the bridge. The wiring diagram is given in figure 8, and symbols are indicated for each of the values. The general equation for the unbalanced current in the flux meter in terms of the resistance in the arms, the flux meter resistance, and current supplied to the bridge, is

$$I_M = I_B \frac{R_4R_1 - R_3R_2}{R_1R_2+R_2R_3+R_3R_4+R_4R_1+R_1R_M+R_2R_M+R_3R_M+R_4R_M}$$

In the construction of the bridge the resistances of the 4 arms are made so nearly equal at zero flux that they may be considered equal. If then x be substituted to represent the resistance of each of the 2 bismuth arms, and if y be substituted to represent the resistance of each of the constant arms, the equation simplifies to

$$I_M = I_B \frac{x - y}{x + y + 2R_M}$$

For this study the bridge was assumed to be unbalanced by a flux which increased the resistance of the bismuth arms 50 per cent. Assuming the supply current to the bridge as constant, the equation was solved for varying values of arm resistance from 5 to 100 ohms and for R_M values of 10 ohms and 27 ohms. The results are shown in curves *A* and *B*, figure 8.

However, in the operation of a bridge too much heating would result if the same I_B values are kept for the higher resistances, unless the size and thus the heat-dissipating capacity are altered accordingly. A second set of computations was made assuming the heat loss as constant, and thus the I_B will be greater than 20 milliamperes for low arm resistances and less than that for high arm resistances. Curves *E* and *F* were calculated assuming a heating loss of 0.0112 watt. This was the loss allowed in the meter built, and also the resulting loss in curves *A* and *B* when the arm resistance was assumed to be 28 ohms.

Curves *C* and *D* assumed half this loss, or 0.0063 watt; curves *G* and *H* assumed double the loss, or 0.0252 watt.

Evidently little is to be gained by using an arm resistance more than 2 or 3 times the flux-meter resistance, even if the bridge current is kept constant for all values. As is also evident from curves *C* to *H*, with a constant loss the arm resistance should be about equal to the flux-meter

Fig. 4. Magnetic flux meter

resistance. Thus a desirable flux meter will have a resistance as small as possible, providing it is at the same time sufficiently sensitive. With such a meter, a bridge can be made which will be both sensitive and very small in size. Such a bridge would be well adapted to measure fields of rather small dimensions, and would give more accurate results in nonuniform fields. Since flashlight batteries would commonly be used as the source of voltage in the bridge, the current value should be kept as low as possible to give the results desired. Also 2 bridges might be used with the same meter: one with very small total area, wound of small diameter wire, the other with heavier wire and thus a much larger total area. The diameter of such a small bridge might be limited to 5 millimeters or less; that of the larger one might be 25 millimeters or more. The former would take less current, would be less sensitive, but could be used in very small field areas. The latter could be made very sensitive by using a large bridge current, but its use would be limited to uniform fields of much larger areas.

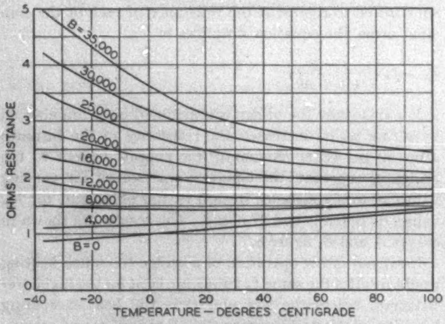


Fig. 5. Variation of bismuth resistance with temperature at various flux densities

Using a resistance of one ohm at zero degrees centigrade and zero flux density (from Smithsonian tables)

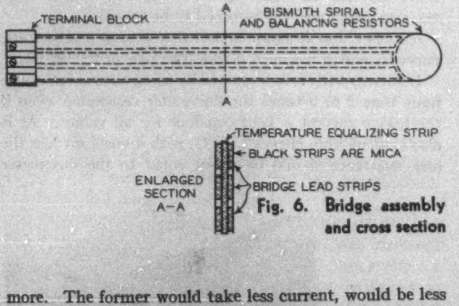
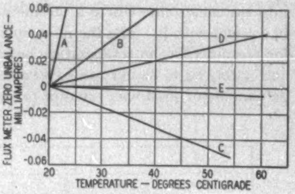


Fig. 6. Bridge assembly and cross section

A given meter may be calibrated to be used for a wide range of measurements. For the calibrations shown in figure 3, the range of the instrument was doubled by a reduction in the current supplied to the bridge. In a similar manner the range could be still further increased to a maximum as high as is desired. However, to obtain a lower range with the same bridge, either a greater bridge current must be used, or a flux meter of the same or greater sensitivity but with lower resistance.

The same bridge used for the curves in figure 3 had a full scale range of approximately 2,000 gausses when used with a Weston model 322 meter, having a resistance of 18.4 ohms and a full scale reading of 0.1 milliampere. By increasing the current to the bridge from 21.3 to 30 milliamperes the full scale range was further reduced to approximately 1,700 gausses.

Fig. 7. Zero drift with temperature change



Type and value of balance arm resistors:

A—Manganin, equal to bismuth

B—Tantalum, equal to bismuth

C—Copper, equal to bismuth

D—Nickel, approximately 18 ohms each

E—Nickel, approximately 22 ohms each

The final balance was too near zero to be shown on curves

Some work was done in determining the amount of current which could be used before the heating is noticeable or dangerous. A piece of the 0.17-millimeter bismuth wire was soldered to light copper leads, and was formed into a small loop with a thermocouple inside the loop. The whole was cemented between thin mica sheets. The results showed that up to 50 milliamperes no appreciable temperature rise was noticed, and that at 75 milliamperes the temperature increased only about 2 degrees centigrade above a room temperature of about 21 degrees centigrade. The current was increased to 800 milliamperes; after about 20 minutes the wire was very hot, but still was in no danger of melting or burning out. In operating the bridge at 20 milliamperes no noticeable temperature rise takes place, and possibly higher currents could be very safely used.

For calibration purposes an electromagnet was built to give a flux density of at least 20,000 gausses between the parallel circular pole pieces, 3.8 centimeters in diameter, when the air gap between them is set at 5 millimeters. From this diameter the pole pieces taper outward at the Ewing optimum angle of 51 degrees to a final diameter of 7.6 centimeters. This setting results in a very uniform air-gap flux between the parallel faces. A one-turn search coil 2.9 centimeters in diameter is hinged on an arm and, by means of a catch, is held well within the uniform portion of the field. Beside it may be placed other measuring devices for comparison or calibration. Upon release of the arm, the search coil is automatically swung out into

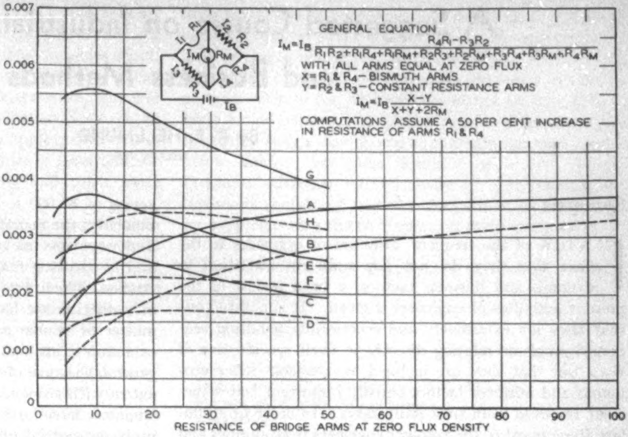


Fig. 8. Bridge sensitivity curves

Variation of I_M with varying resistance in the bridge arms

R_M = 10 ohms for all full-line curves

R_M = 27 ohms for all dashed-line curves

For curves *A* and *B*, I_B was assumed constant at 0.02 ampere for all values of resistance. The I_B current values for the other curves were computed to maintain the *RI* constant

Curves C and D—RI_B^2 = 0.0063 watt

Curves E and F—RI_B^2 = 0.0112 watt

Curves G and H—RI_B^2 = 0.0252 watt

a zero-flux field by means of a spring, and the impulse due to the induced voltage is read on a ballistic galvanometer.

To calibrate the galvanometer, a standard solenoid was very carefully constructed with length 174 centimeters and diameter 7.9 centimeters, giving a ratio of length to diameter of 22 to 1. The calibration constant of the galvanometer and search coil obtained by means of the standard solenoid was 1,844 gausses per unit deflection on the galvanometer. This appeared to be fairly constant for deflections up to 4 or 5 units, but decreased by small measurable amounts at the higher values.

A calibrated bismuth spiral just received from Germany was used as a check on the ballistic method. Table I gives the results of a very careful check made between the 2 methods.

The lowest flux-density value results in a constant slightly over 2 per cent greater than the calculated one; values at the higher densities more nearly check the calculated values. As appears in table I and as was previously mentioned, the constant becomes smaller at the higher galvanometer deflections. As a compromise between the 2 methods, a curve was plotted of constants against galvanometer deflections, the values of which were taken as a reasonable mean between the 2 methods.

A considerable number of calibration data were obtained on the various bridges tried, under various temperatures and other conditions. Unusual care was taken in obtaining the curves shown in figure 3. Several check curves were taken at 22 and 30 degrees centigrade, some by means of the German spiral only and others by means of the galvanometer. Very few of the points thus obtained varied more than 1.5 per cent of full scale value above or below the mean curves, and most of the values fell on or very near the curves shown. From all the experience gained in the use of the bridge the conclusion seems reasonable that the meter will duplicate its readings to a greater degree of accuracy than can be expected from the usual calibrating apparatus, which probably ranges close to 2 per cent.

A summary of the advantages and disadvantages of the meter—most of which have been indicated in this discussion—makes evident that by the use of 2 bismuth elements instead of one, the indication for a given flux density value is very greatly increased, and that it arrives at its final value almost as soon as the element is placed in the field, remains constant if the field is constant, or varies with the field if the change is not too rapid for the meters to follow. If the various arms of the bridge are so constructed that the changes due to temperature are similar in each, small temperature changes, so troublesome with a single spiral, are entirely, or almost entirely, obviated. A single bridge and meter may be calibrated for a very wide range of flux densities, from the lowest the meter-and-bridge combination will give to the highest desired. By including more than one bridge with the same meter, the combination can be adapted for measurements in very small areas, as well as for larger areas of comparatively low densities. Probably the greatest disadvantage of the meter is the change in the indication for a given flux density when the bismuth temperature is changed either above or below that at which the meter is calibrated. Where great accuracy is desired readings must be corrected

Table I

Flux Density by Bismuth Spiral	Galvanometer Deflection by Search Coil	Resulting Galvanometer Search Coil Constant
2,490	1.32	1,885
7,500	4.00	1,874
10,270	5.55	1,850
11,300	6.14	1,843
14,500	7.83	1,851

(*Concluded on page 475–6*)

A Suggested Course on Industrial Economics and Business Methods

By R. E. HELLMUND
FELLOW AIEE

Synopsis

IN VIEW of the frequent criticism of engineers to the effect that they do not pay sufficient attention to economic and business factors, a brief review of the present activities of engineers is given. It is pointed out that they are extensively and successfully handling economic problems relating directly to their specific line of work but that they are inclined to overlook other economic and business factors equally important but somewhat removed from their daily tasks. In order to stimulate the interest of the younger engineers in economics and to give them a broader viewpoint of the business enterprises in which they will be engaged, a brief but fairly comprehensive course on "industrial economics and business methods" is advocated to be given in preference to some of the highly specialized technical courses now forming part of the undergraduate curricula. The paper outlines the type of subjects which seem suitable for this course and further recommends that analytical methods of attack be employed to a greater extent than is now customary in economic studies.

The general criticism of engineers during recent years to the effect that they have not paid sufficient attention to economic and business factors surrounding their work is a challenge to the engineering profession. This criticism has almost created an impression that economic considerations are more or less foreign to practicing engineers. However, even a cursory examination of actual conditions shows that this is far from the truth. An industrial plant engineer, for example, when considering the installation of a power plant, will make very extensive and detailed economic calculations covering various plans. His studies probably would include a comparison of the economic merits of power purchased from a public utility and that generated in a privately owned plant, as without this information it is not likely that any management would appropriate funds for the undertaking. In fact, an appreciable part of the time of most plant engineers who deal with the purchase and installation of any equipment is devoted to economic studies of some kind or other. If we now turn to the design engineer, we find that he too spends a large part of his time in working out the most economic designs and in analyzing items affecting costs. A designer of household refrigerators, for instance, would not hold his position very long if he did not devote a great deal of his time to economies in design. When it is considered that with the quantities produced by some manufacturers a one-cent saving on each unit means an annual saving of $1,000 to $4,000, the need for this is obvious. Similarly, the manufacturing engineer tries continually to find ways and means for reducing manufacturing costs and in so doing makes numerous comparative economic studies. The utility engineer, in considering the extension of a distribution line to reach new customers, will as a matter of course make calculations to see whether the extension is justified from an economic point of view. In general, the time of most engineers is taken up to a great extent with economic considerations, and the majority of engineers have furthermore proved well able to cope with problems and calculations of this nature. The analytical methods required for this purpose are much simpler from a theoretical point of view than many other problems that engineers have to solve in their daily work.

Nevertheless I am in accord with those who feel that engineers should interest themselves to a greater extent in economic factors, and the suggestion frequently offered that the curricula of engineering schools be modified to bring this subject to the foreground seems a step in the right direction. Engineers who successfully handle certain economic problems too often entirely overlook other economic and business aspects, or at least do not sufficiently appreciate their importance. It is not at all uncommon to find designers who spend much of their time in devising machines that can be economically built and operated advocating commercial or engineering ventures which as a whole are economically unsound. As an illustration: In these days when air conditioning is receiving wide attention, endless schemes which could not possibly be commercialized within a reasonable period of time are being proposed by serious and capable engineers. Proposals are being made, for instance, to install internal combustion engines in homes or small commercial establishments for the purpose of furnishing both heat and electric power, and extensive studies are being made to improve the thermal and electric efficiencies of these arrangements. At the same time, the fact that this apparatus at present cannot be manufactured, marketed, and installed under a cost of several thousand dollars is being entirely overlooked. This in turn means that the interest on the investment and the allowance for depreciation and maintenance would about equal the cost at which these services can now be obtained more conveniently by using one of the existing methods of heating and by buying power from a public utility. The proponents of

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1. For all numbered references see list at end of paper.

these arrangements will at times give consideration to the cost of the production of the equipment but will often entirely ignore the expense involved for sales effort, warehousing, shipping, installation, and servicing of the equipment. If this is brought to their attention, they will pass it over by stating that the distribution costs can be held low and they seem to have no appreciation of the fact that the reduction of these expenses is more difficult than the reduction of manufacturing and other more tangible factors of expense.

Similarly, the engineer who purchases equipment often acts contrary to sound economic laws by ordering special apparatus when standard apparatus would be satisfactory and more economical. The sales engineer in his eagerness to secure business will agree to furnish specials when it is obvious that this means additional expense to the manufacturer and that in the long run these expenses will be passed on to the purchaser. This practice of increasing the manufacturing cost is frequently followed by engineers who will on the other hand go into the most minute details in calculating economies in their own part of the undertaking.

This inclination on the part of the engineer to study economic factors having a direct bearing on his own work and to pay so little attention to other equally important ones entering into an enterprise is, of course, not greatly different from that found in other forms of human endeavor. It is a common failing of human nature to give undue emphasis to factors of direct and immediate interest and to overlook others of equal or even greater importance. The most natural way of eliminating this shortcoming would seem to be to give the engineer a broader point of view of industrial economics during his early education. Some schools have departments for industrial engineering in which courses relating directly or indirectly to specific phases of industrial economics are given. The titles of some of these courses indicate a rather broad study, but they are often found to be limited in scope. Nevertheless, industrial engineering students whose programs include a number of these specific courses may carry away with them a reasonably broad conception of the important factors entering into industrial economics. A review of the curricula of other engineering departments, such as the electrical, mechanical, and civil engineering, indicates that but one or 2 courses relating to a more or less specific phase of industrial economics are listed as electives, and that in a few isolated cases one or the other of these courses is compulsory. This practice, however, falls short of the previously indicated need for giving the student a broad point of view in industrial economics. In order to satisfy this need, a fairly comprehensive course on "industrial economics and business methods," relating primarily to the problem of the supply and use of manufactured goods or articles, should be given to students of electrical, mechanical, and chemical engineering. This course may also be helpful to students of civil engineering, although the interest of civil engineers is more or less confined to the use of manufactured goods and problems relating to their production are of less importance to them. It is evident that a course of this nature cannot possibly cover all phases of economics, nor can it treat any phase in detail because of the endless variety of economic problems arising in industry. Nevertheless it is believed that in a 2-hour course carried through 2 semesters, many important subjects can be covered and the student given a fairly broad perspective. An attempt will be made here to outline such a course and to indicate the type of economic studies that seem desirable as a part thereof. Frequent reference will be made to publications and textbooks containing material that seems to be suitable for supplementing the brief remarks and principles stated in the following.

The essential factors of industrial economics include:

Supplying goods
- Direct labor
- Works overhead
- Materials
- Test and inspection
- Design, engineering development, dies, and fixtures
- Storage, distribution, and servicing
- Installation

Using goods
- Interest charges on investments
- Depreciation
- Operating expenses
- Maintenance expenses
- Scrap value

Factors of interest to both *supplier and user*
- Statistical methods
- Standardization
- Organization
- Personnel questions, etc.

Problems relating to the *over-all operating results* of the individual economic units
- Price limitations
- Business volume
- Expense control
- Budgeting, etc.

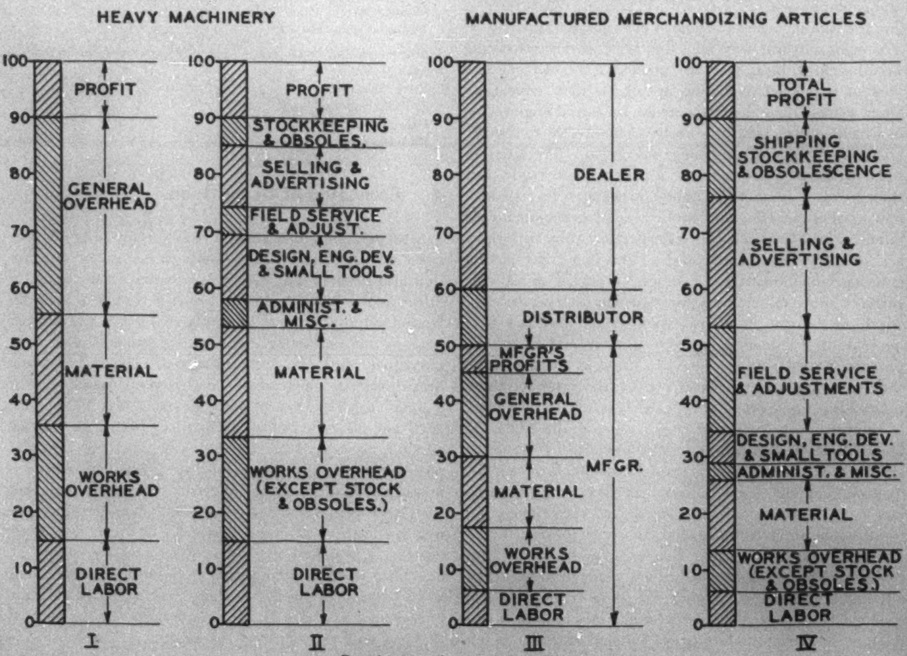
A. Economics of Using Goods

Although, chronologically, the supplying of goods precedes the use of them, the supplier should give consideration first to their use. Goods are created for some use or other and only those goods which accomplish their intended purpose in the most economical manner are worth creating and marketing. The user of goods is, of course, interested primarily in this phase of economics. Often his problem is to determine whether goods purchased for a given purpose represent an economic undertaking on his part, and he should in all cases select from a number of possible choices the goods that will most economically serve his specific purpose, regardless of whether a business problem or his personal comfort or pleasure is involved. The basic principles governing these considerations are well set forth in available textbooks and therefore need not be covered here in detail. (See references 1 and 2; an abbreviated version giving the essentials presented in chapters 1 to 10 of reference 1 seems well suited for presenting this material. See also chapter 2 of reference 27 for a brief treatment of the subject.) The considerations of the user relate in the majority of cases either to but one or to a limited number of specific applications, but the supplier's problem is much more complex. He is often confronted with the necessity of considering a great many uses of a proposed article of manufacture under various conditions of application and as affected by many economic factors. It is necessary for him to make a rather complete market analysis in order that he may supply goods which will be applicable by many users and which can therefore be manufactured in quantities sufficiently large for successful commercial exploitation. The manufacturer's point of view and methods of analysis are covered in some of the available textbooks. (See in particular reference 14, chapter 4. The considerations given in this reference apply essentially to equipment used in industry but the fundamentals apply equally well to manufactured goods of the so-called "merchandising" type used by the public at large.)

B. Economics of Supplying Goods

1. Cost and Expense Factors

In a study of the economics of supplying goods, the cost factors entering into the manufacture of industrial goods should be briefly reviewed. (See, for example, chapter 7 of reference 3.) However, the distribution of goods also is very important from an economic viewpoint and the discussion should be extended to cover this phase as well. Graph I shows the cost distribution as it may apply to the manufacture and marketing of a heavy piece of machinery. This graph is in accordance with the customary accounting practice but gives only the major divisions, showing the 3 major cost factors relating to works production and giving as a single item all other factors entering into the total cost to the manufacturer under the assumption that he sells directly to the ultimate user. In graph II, the items given as "general overhead" in graph I are further subdivided, and the expense for stocking and obsolescence of stock usually involved in the handling of certain part stocks in the works organization is combined with the other expenses for stocking and obsolescence. The principal purpose of showing the expense in this manner is to stress the fact that there are, in addition to the usual manufacturing activities in industry, a number of other very definite and unavoidable functions presenting economic problems of great practical importance. Graph III shows the segregation of expenses as they quite commonly apply to merchandising articles, which require the service of distributors and dealers in addition to the function of the manufacturer in order to meet the demands of a broad market. With articles like this, certain selling and advertising expenses may be encountered by the manufacturer, distributor, and dealer, and therefore graph IV has



Distribution of customer's dollar

been drawn combining these expenses as a single item; shipping, stocking, and obsolescence as another; and field servicing and adjustment expenses as a third. This again shows that expense items other than those for manufacturing are of even greater importance than those shown in graph II. Because of the difficulty in obtaining accurate data from all 3 parties involved, no claim can be made for the accuracy of the proportions shown; however, it is believed that they are nearly correct for certain merchandising articles. These graphs are given because no suitable references could be found elsewhere.

Each of the items shown in graphs II and IV involves a number of further subdivisions, each having its own economic aspects, and it is obviously impossible to discuss all of them in a brief course. However, it seems desirable to exemplify the general principles involved by an analysis of some of the more important subdivisions and merely to mention some of the other problems of an economic nature.

2. DIRECT LABOR

In the labor item, rate setting for the shop personnel is one of the most important factors subject to economic study. A great deal has been written about this (references 4, 5, and 6) and excellent results are now being obtained in this work. This subject should be covered briefly in the course (see reference 4, chapters 16 and 17). Closely tied in with the subject of rate setting is that of incentives (briefly covered in reference 4, chapter 39; see also reference 27, chapter 21). In this connection, the economic influence which incentives for speed may have upon quality and the consequent need for additional inspection and field adjustment expense, should be carefully considered. In the labor study, certain relations between production factors and the law of diminishing returns are of practical importance (chapter 8, reference 3) and may be discussed here although the broad principle applies to many activities. Another item of importance in labor costs is the determination of lot sizes giving the most economic results (reference 7). Consideration of suitable methods and equipment for all manufacturing operations and the economics of handling parts and complete pieces of apparatus in their flow from one manufacturing operation to another (reference 27, chapters 13 and 14), as well as comparisons of the merits of centralization and decentralization of some maufacturing operations (reference 24), are all essential in studies of labor expense.

3. WORKS OVERHEAD

Equipment for manufacturing purposes represents an important item affecting works overhead. A plant engineer in considering the installation of equipment for manufacturing operations usually acts as the user of products manufactured by others and he thus makes use of methods previously referred to in the "Economics of Using Goods." In addition, he must of course compare the overhead expense caused by different types of equipment with the savings in labor costs that can be realized with each type. (See reference 27, chapter 8.) These calculations, which must allow for such factors as interest, depreciation, maintenance, cost of power, replacement, etc., are usually specific for each case, but there are basic principles which apply to all of them. (See references 1 and 8; also chapters 9, 10, 11, and 12 of reference 27.) New manufacturing equipment is an item in works overhead which must be taken into account at rather frequent intervals. There are also many other items, such as depreciation in buildings, insurance, lighting, cleaning, supervision, which require analysis less frequently but which must be reviewed at the proper time. As an example, the construction of a plant and its best geographical location involve a great many economical problems, some of which have an important bearing on works overhead expenses (reference 27, chapter 3).

4. MATERIAL COSTS

The material content of any manufactured article is essentially a question of design, with problems more or less specific to each case. However, important general economic considerations enter into this, such as methods of standardizing and stocking raw materials which will make available a sufficient variety of materials to permit satisfactory and economical design and at the same time limit and rationalize available types and sizes of materials. This is of prime importance in reducing expenses for storage and investment and makes possible the purchase of material in large quantities, with corresponding reduction in price. (See reference 9; also chapters 6 and 7 of reference 27.) The purchase of material again involves numerous economic considerations. The methods of purchasing and the underlying basic principles represent an extensive study in themselves; only a brief reference to some of the basic considerations seems justified. (See second half of chapter 6, reference 27; for additional material see reference 22, chapters 1 and 2, and possibly reference 23, chapters 8 and 9.)

5. TEST AND INSPECTION

Proper inspection and testing methods for manufactured articles and parts require detailed study and are referred to separately because the expense for these activities is at times considered part of the labor cost, at times part of the cost of materials, and in other cases as a works overhead item. It is evident that articles should not be marketed without assurance, through inspection and test, of satisfactory field service in the majority of cases. Any appreciable amount of difficulty in the field will lead to uneconomical results through field expense and adjustment and the loss of the goodwill of the customer and, as a consequence, to increased sales resistance and sales expense. On the other hand, a method of inspection and testing giving 100 per cent satisfaction in the field may prove so costly as to be uneconomical from an all-round point of view. It is therefore highly desirable to devise inspection methods which strike the proper balance between the 2 extremes. Through the proper utilization of statistical data, a good deal has been done recently to put inspection activities on a more or less scientific basis and a brief study of material of this nature as part of a course on economics seems desirable. (See references 10 and 11.) While inspection activities are usually associated with the manufacture of goods, suitable methods are also of value to the users, who quite frequently find it expedient to undertake inspection and check tests of their own.

6. DESIGN, ENGINEERING DEVELOPMENT, DIES AND FIXTURES

It is obvious that many economic considerations enter into design and engineering development activities. It has always been the major activity of the design engineer to develop apparatus which not only is effective and economical for the intended purpose but which also, through minimum expense for labor and material, can be produced cheaply. Apparatus must also be designed so that it requires the minimum expense for shop equipment and consequently low works overhead. The considerations vary to a great extent with the type of apparatus involved and can hardly be made the subject of a general study. However, a general activity which is becoming of increasing importance in economical design is that of carefully planning the design of an entire line of apparatus with all anticipated variations. With the continually increasing variety of sizes and ratings required, the multitude of service conditions to be met, and many other factors adding to the complexity of the problem as a whole, this procedure is essential. Not so long ago it was customary to design more or less independently the various sizes of a line of apparatus to meet the usual and standard requirements and subsequently to modify such designs to meet special requirements. This method of attack may still be satisfactory in cases where one type of design and possibly a few sizes or ratings represent the major part of the entire demand and where special requirements are the exception rather than the rule. In these cases, consideration of the standard variety should predominate and the few exceptions can be made the subject of secondary consideration. However, in the majority of cases such conditions no longer apply and a much better method of attack consists in designing a line of standard parts which are flexible in their use and permit the assembly of the many varieties demanded by the market. In planning a line of parts, a great deal of attention must be given to the simplification of stocking and routing of the parts so as to permit quick delivery of almost any reasonable combination and to the possibility of combining parts readily in a number of assembly plants or in the field, as the case may be. The necessity for meeting the more complex present-day problems should be recognized to an increasing extent by the designer. With the proper appreciation of this, it will usually be found possible through the choice of a rational line of parts of evenly spaced dimensions or characteristics to realize the most economical production of an entire line of apparatus with all reasonable variations rather than the production of a few so-called "standard assemblies" at a minimum cost. This can best be illustrated to the student by a few examples of specific apparatus designed in accordance with the principles previously mentioned (references 12 and 13).

Closely tied in with the development and design of a line of apparatus and usually considered as part of the development cost are the tools, such as dies, fixtures, molds, etc., needed for manufacturing the specific line as distinguished from the general-purpose tools. The expense for these tools can also be materially influenced by the planning of the entire line (see reference 27, chapter 12). Numerous problems arise in the planning of tools best suited to and most economical with the anticipated volume of manufacture, life of the design, interchangeability of parts, etc. As part of all development activities, it is very essential to determine whether the development costs can be recovered within a reasonable period from the sale of the device, the estimated sales volume being based upon previous experience or on a recent market analysis. The engineer's own work must, of course, be so planned that it can be carried on economically, and in addition to the design work, economic methods of making estimates in answer to customers' inquiries must be worked out. It is often difficult to decide whether this work should be carried on more or less completely for each individual project as it comes up or whether it is more economical to prepare extensive data which will facilitate the work in general and reduce the expense for estimating on the individual inquiries. (For additional discussion on estimating, see reference 27, chapter 5.) As part of the estimating and bidding on special apparatus, it is frequently necessary to decide whether it is more economical to accept orders involving highly specialized requirements or to forego such business. Although the decision in these cases is frequently influenced by competitors' practices, a good fundamental rule for the engineer to follow is to assume a sympathetic attitude toward those requirements for which there is economic justification or a real need and which therefore warrant a price sufficiently high to cover at least part of the extra costs of development or manufacture. (For additional discussion on engineering work, see reference 27, chapter 4.) Industrial research can be considered as part of engineering and it also has its economical aspects (see reference 27, chapter 16). However, as it is usually difficult to find a definite measure for the benefits derived from research work, it is not easy to determine just how much an industrial enterprise can afford to appropriate for this purpose.

7. STORAGE, DISTRIBUTION, AND SERVICING

The economic problems relating to marketing and its subdivisions, such as selling and advertising, shipping, stocking, and obsolescence, installation and field service and adjustments, are often less tangible and therefore more complex and difficult than those previously discussed. This is no doubt one of the reasons why they have been subject to less analytical treatment, as a result of which less progress has been made in finding economic solutions for the many problems and in the reduction of the high costs of distribution. This, however, only emphasizes the importance of these problems and the advisability of giving them an appreciable amount of time in a comprehensive course on economics, which is further supported by the fact that a large percentage of engineering graduates take up this work after entering industry. Although there is a good deal of literature available on the marketing of so-called "merchandise" and various business courses given at the colleges treat this subject extensively, comparatively little has been written regarding the marketing of industrial goods. However, a few good books covering this subject have been published recently and liberal use should be made of their contents in bringing before the engineering student the importance of marketing problems relating to equipment originated by engineers. (See references 14, 15, and 16; in particular, chapters 5, 6, 8, and 9 of reference 14 and chapter 2 of reference 16; also chapter 17 of reference 27.) The references given relate to the marketing of industrial equipment to industry, but it seems that there is practically nothing available on the marketing of highly technical industrial goods, such as refrigerators and electrical heating devices, to the public, though the problems in connection with this activity are becoming of increasing importance. It is evident that the methods of marketing these articles to the public differ greatly from the marketing of regular consumption merchandise, such as food, articles of apparel, and the like, and that they therefore deserve separate and thorough consideration.

In the sale of industrial products, which activity in the case of industrial products is carried on principally by engineering graduates, the success of the sales engineer depends to a great extent upon his ability to analyze his customers' problems properly from an economic point of view. It is therefore essential that he be familiar with a great many of the factors and methods of analysis outlined for the proposed course.

8. INSTALLATION

The installation and also the proper application of industrial products may in many cases be a major, or at least an appreciable item of expense. This expense will be incurred by the manufacturer, distributor, dealer, contractor, or user. Important economic problems may be involved but these are so varied and numerous that it is difficult to outline even the more important considerations in the brief course under discussion.

C. Interrelation of Economic Factors

The divisions given in the graphs and discussed in the foregoing, as well as the divisions of most accounting practices and systems, represent an attempt to segregate various major types of costs or expenses and to place the responsibility for these various expenses upon the different departments of an industrial organization, such as the works, engineering, sales, and executive departments. However, these purposes are accomplished only to a limited extent, and it moreover appears to be practically impossible to devise any system which permits even an approach to a clean-cut division of responsibility among the various functional divisions of an organization. It is true that items such as labor, material, and works overhead are usually considered the major responsibility of the works organization, but the previous discussion indicates quite clearly that these items are about equally dependent on the activities of the design engineers. (Additional evidence supporting this can be found in reference 17, for instance, or reference 27, pages 52 to 58.) Similarly it can be shown that the engineering department's work appreciably influences the economic factors relating to marketing. The engineer's success in meeting, or his failure to meet, the requirements of the market and in designing for sales appeal will greatly influence the market acceptance or the sales resistance encountered and consequently will materially affect the sales expense and also the volume of sales. The latter, in turn, will indirectly influence the cost of production and so forth. The engineer also influences to a marked degree expenses for field service, field adjustments, and installation. Finally, the engineer, particularly in his ability to design parts and devices permitting flexibility of assembly and application, may affect expense for stocking, shipping, etc., appreciably and also the possibility of quick deliveries, which will directly affect sales volume and, indirectly, various production cost factors. There are few economic factors in industrial activities which are not influenced to some degree by the design and development engineer. The same holds true of the activities of the works organization. Faulty workmanship or material will result in expenses for field adjustments and will increase sales resistance and other unfavorable influences; similarly, inability to make quick deliveries because of some shortcoming of the works organization will bring with it unfavorable economic results. The sales organization in turn can materially increase engineering and development expenses by requesting estimating when there is no reasonable prospect of obtaining orders, or by accepting orders for special apparatus when standards might be sold. Examples of the influence of the activities of one division upon the economic operation of other divisions could be cited almost indefinitely. This very condition, which is practically unavoidable in modern organizations with functional activities, makes a comprehensive course on industrial economics and business methods highly desirable in an engineering curriculum. As pointed out in the beginning of the paper, almost any department can handle its own major economic problems satisfactorily, but much improvement seems possible through appreciation by any one department of the effect of its activities upon the economies of other departments.

D. Miscellaneous Factors of Economic Importance

In addition to the activities discussed, there are a number of others the responsibility for which it is difficult to place with any one division of an organization. In these cases, results can be obtained only through the co-operation of several divisions, or perhaps even though the co-operative action of persons throughout the entire industry. Under these conditions, it is of course difficult to work out an economic solution of the problem at hand. The most outstanding item of this nature is standardization, and no course in industrial economics can be considered complete if it does not devote appreciable time to the economic possibilities of proper standardization. Not only should the value of standardization be pointed out (see reference 3, chapter 9), but methods facilitating standardization also should be given, such as the use of simplified practice and the application of preferred numbers (references 18 and 19; also chapter 15 of reference 27). An essential step in standardization frequently consists in the choice of proper standard sizes and ratings with satisfactory steps between. This is very important from an economic viewpoint (reference 20 or 21). Some problems involved in standardization have been previously referred to in the discussion of the standardization of materials (reference 9) and the standardization and design of parts permitting flexible assembly (references 12 and 13).

Another factor which is of economic importance and which cannot be handled by the individual units is that of organization and the proper correlation of the various units to facilitate the work. The course, therefore, might make reference to different types of organization (reference 3, chapter 11). Unfortunately various treatments on organization in available textbooks are merely of a descriptive nature and some authors of articles or papers are prone to advocate in a controversial manner organizations of some particular type. In considering various types of organization, it is essential to recognize that any one of them may result in the best economic results under certain conditions, and, furthermore, that within the larger industrial organizations nearly all types of organization can be used to advantage for different activities and at different levels of the organization. For example a large company may be divided into various units, each producing a certain line of products while within each unit the organization may be along functional lines. In addition, it may be and usually is advisable to have a staff for co-ordinating certain functional activities of the various units as well as certain centralized functional activities. It is most essential that any treatise on organization should give, in addition to a description of the various types, some consideration to the factors influencing the choice of one rather than the other type of organization for any set of conditions.

Other activities usually not associated with economics nevertheless have economic aspects which may be pointed out briefly. Examples are: personnel questions, educational and training activities, and even social and welfare arrangements. (See chapter 20 of reference 27, also chapters 13 and 19 of reference 25 or chapters 14, 17, and 20 of reference 26.) The expenditure for educational activities, for instance, should be in keeping with the subsequent savings derived from having the work performed by a personnel which has benefited from such education.

E. Analytical and Mathematical Treatment of Economic Studies

In reviewing material available on industrial economics, it has been observed that too much of it is of a descriptive nature and that there has not been much attempt to attack the problems in an analytical manner. As just indicated, the treatments of organization, for instance, are frequently descriptive or of a controversial nature and lack the objective and analytical point of view which the engineer should have in all of his work. In many instances it is quite possible to attack a problem by mathematical methods, and this is advisable even though a complete mathematical solution is not possible. Frequently even a partial mathematical solution establishes certain facts, which with the use of good judgment regarding other factors is much more likely to give better results than relying entirely on judgment. (For examples of this see references 7 and 20 or 21, also some chapters of reference 27.)

The analytical treatment of many economic problems will eventually be dependent upon statistical data and statistical methods of using these data, and for this reason some time should be given to a study of such methods, reference to which has already been made in the discussion of test and inspection (references 10 and 11). Other presentations of statistical methods for engineering problems have been published (see reference 1, chapter 14).

F. Basic Considerations for Economic Units

An economic unit as referred to here may be an individual, a household, partnership, or a company; again, it may be a municipality, a state, a society, etc. The previous outline clearly indicates that economic considerations enter into nearly every activity connected with an industrial product, from its inception, design, or development to the time it is used up and ready for the scrap pile or to be disposed of in some way or other. Various and typical examples of economic questions have been discussed. Assuming that all industrial activities are carried out with due consideration to economy, it is further most essential that the over-all picture be sound from an economic point of view. If we assume, for instance, the simplest case where all activities are carried on within a single industrial unit, this means that the cost of creating a product must be equal to or below a value justified by its use. In addition, it is necessary that the concern involved either has the funds required to finance the venture or can convince others of the soundness of the venture and thus obtain funds from them as an investment or a loan. In most cases, however, conditions are not quite so simple inasmuch as several economic units are involved—sometimes a manufacturer and a user; again, both of these and a dealer or distributor, or both; or there may further be contractors, contractor dealers, and several other types of economic units having a place in the over-all picture. In all these cases it is necessary not only that the over-all picture of the product be sound but also the part of the work carried on by any of the individual units and the operation of each unit as a whole be on a sound economic basis. No type of unit can survive unless the other types necessary for the complete picture are able to do their part; for example, a manufacturer unwilling to give his dealers a discount which will enable them to carry on their part of the activities with a reasonable profit cannot hope to survive.

As previously pointed out, the most important economic factors of the entire picture to be considered first are those determining the amount which the user can or will pay for a product. In the case of well-established goods for which there is a general demand, the price obtainable by any supplier is usually fixed by competitive prices, with proper allowance for difference in quality, serviceability, and similar factors. Such competitive prices as a rule drift around a level where the more efficient suppliers make a reasonable average profit. If the user is an industrial concern, the price must further be such as to make the purchase a profitable economic venture for the purchaser, based on the considerations covered under "Economics of Using Goods." In the case of individuals or homes, additional limitations are imposed by the income of the purchaser, which is comparatively low in the majority of cases. The price obtainable and the volume of sales at such price depends upon the number who are willing to pay and the amount they are able to spend for conveniences, comforts, and luxuries after paying for absolute necessities.

In view of all these and other factors limiting the price obtainable, the supplier's principal economic problem is to bring the cost of all his operations sufficiently below such price to allow a fair profit. Whenever several units, such as the manufacturer, distributor, dealer, and others, are involved in the marketing of a product, the first problem is to determine the proper distribution of the customer's dollar among these units. Subsequently each unit is confronted with the problem of carrying out its part of the functions at a cost sufficiently below the part of the customer's dollar allotted to it to insure a reasonable profit, or at least sufficient to give a fair return on the capital required for carrying on the particular activity. There are always a few exceptions to every rule, and in the case of new products of low cost and great usefulness it is sometimes possible to secure larger profits. This, as a rule, is only a temporary condition, because the very possibility of larger profits encourages competitive enterprises and consequent reduction in price. At times patent protection makes it possible to maintain larger profits for an extended period, but even in these cases attractive profits usually stimulate competitive inventive activities which eventually lead to the manufacture of similar products by others, with a resultant reduction in prices. Even during the periods when it is possible to secure large profits on the individual article, better all-round economic results can often be obtained by the manufacturer through the lowering of prices, with subsequent greater sales volume, lowered cost of production, and increased overall profits.

An outline of these considerations seems essential as a part of the proposed course and is given here in some detail because no suitable references could be found. The growing appreciation of the fact that prices and profit margins in most industries are continuously decreasing and likely to change into losses, especially during business depressions, has developed a tendency toward budgetary control of all expense and cost items, such as those shown in the graphs and many others. Continually changing business conditions naturally make it difficult to budget expenses in advance. Furthermore, too rigid a budget control carries with it the danger of interference with freedom of action when circumstances arise making departures

Table I

Period Number	Subject	Part of This Paper	Numbers of Typical References	Numbers of Alternate and Additional References
1 2 3 4	Introduction and standardization	Introduction and first part of *D*	3, chapter 9; 19 and 20	27, chapter 15; 18 and 19
5 6	Organization and personnel	Part of *D*	3, chapter 11; 25, chapters 13 and 19	26, chapters 13, 17, and 20; 27, chapter 20
7 8 9	Engineering application of statistical methods	*E*	1, chapter 14	
10 11	Inspection and test	*B*-5	10 and 11	
12 13 14 15 16	Economics of using goods	*A*	1, chapters 1–10; 14, chapter 4	1 and 2; 26, chapter 2
17 18 19	Expense factors Labor	*B*-1 *B*-2	3, chapters 7, 8; and 4, chapters 16, 17, and 39; 7 and 24	27, chapters 13, 14, and 21; 5 and 6
20 21	Works overhead	*B*-3	27, chapters 3 and 8; 8; 1, chapters 1–10	27, chapters 9, 10, 11, and 12
22 23	Materials	*B*-4	22*i*, chapters 1 and 2	27, chapters 6 and 7; 23, chapters 8 and 9
24 25	Design, development—dies and fixtures	*B*-6	12 and 13; 27, chapter 5	27, chapters 4 and 16
26 27 28 29	Storage, distribution, servicing, and installation	*B*-7	14, chapters 5, 6, 8, 9; 16, chapter 2	27, chapter 17; 14, 15, and 16
30	Interrelation of economic factors	*C*	17	27, pages 52–58
31 32	Economics of units—budgeting	*F*	29, chapters 5, 6, and 7	22-*k*; 28
	General references			22, *a*–*k*; 30 and 31

The order of subjects in this table is somewhat different from that in the text; it is here arranged to give in the first semester subjects of interest to both users and suppliers and also on the economics of using goods; in the second semester, the economics of supplying goods is covered.

and changes desirable during a budgetary period. Nevertheless a gradual evolution toward methods of expense control which are sufficiently flexible to take care of changing conditions but not so flexible as to make the control ineffective seems a step in the right direction. Therefore a brief study of this subject of budgets is desirable as a part of the course under discussion. (See references 22*k*, 28, and chapters 5, 6, and 7 of reference 29.)

G. General Discussion

No mention has been made in this outline of the economic problems applying specifically to the central station industry and its production and rate-setting activities. The outline suggested has been worked up with the idea of its being of use to all branches of engineering, such as electrical, mechanical, chemical, etc. Each of these in turn may involve economic problems more or less specific to it, such as the central station situation, which is of specific interest to electrical engineers entering the utility field. Possibly a number of courses of interest to specific types of engineering students should be offered as electives in addition to the more general course covered here; for example, a course relating to the economics of construction work might be desirable for the students of civil engineering.

Scarcely any reference has been made to economic laws and factors as, for instance, price fluctuations as influenced by the law of supply and demand, which are usually covered in existing courses on classical economics. It is assumed that the student has previously taken a course of this nature.

While this entire paper emphasizes economic considerations, care should be taken not to leave with the student the impression that all activities and practices in industry can be governed entirely by economic aspects. There are other factors which must be taken into account and several of the references given introduce points of view other than the purely economic. However, it is usually good practice in any problem or undertaking to analyze the economic situation fully and subsequently give consideration to other factors.

A review of the material given in this paper for use in a course on industrial economics and business methods might give the impression that it cannot be readily covered in a weekly 2-hour period extending through 2 semesters. However, by properly condensing the material of the references this is quite possible. Although the author has not given a course exactly as outlined here, he has given similar courses and has accumulated experience definitely demonstrating the possibility of this. Table I gives a tentative outline indicating the time which might be devoted to the various subjects. In choosing material from the references and from the content of the paper, it is more important to select it so as to illustrate sufficiently the types of economic problems and proper method of attack than it is to give an exhaustive treatment of any one of them. It also seems advisable to make predominant those economic problems which can be handled or are influenced by the rank and file of an organization in order to avoid a rather common impression among younger engineers that most economic problems are essentially a function of the management group. It has been impossible for the author to review completely all material published which might be used for the course, and the references are given principally for the purpose of suggesting the kind of material which seems desirable for this purpose; no doubt other publications of similar nature can be found which at least in some instances may prove to be more suitable for class work than that given. (See reference 22, *a* to *k*, for additional material; reference 31 gives a broad and most interesting study of American industry.)

This paper is intended merely as a contribution by one who has had practical engineering experience, and outlines subjects regarding which the young engineer entering industry should have an appreciation and understanding. It may be true that much of this material will come to the attention of most practicing engineers over a period of years, but frequently the younger engineer will be placed for extended periods in specialized work with but little contact with other divisions of the organization and he would be greatly benefited in carrying on his specialized tasks if he could bring with him some knowledge of the typical economic factors of importance in industry. (See reference 30.) It also seems that with an increased interest in economics the engineering profession could through its analytical methods of attack assist in working out more nearly correct solutions for the many perplexing economic problems in industry.

There certainly can be no doubt that a course as here proposed will be of benefit to a vastly larger number of the younger engineers than some of the specialized technical courses on such subjects as transmission engineering, electric railway engineering, communication engineering, etc., which are now taking a part of the student's available time in college. This fact cannot be ignored and steps should be taken at least to make such a course available as an elective subject and to encourage the students to take an early interest in the economic and business side of their future work.

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(*Concluded on page 475*)

End-Winding Inductance of a Synchronous Machine

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Introduction

IN PREVIOUS PAPERS it has been found necessary to consider the armature inductance of salient-pole synchronous machines under several divisions. The most useful and generally accepted divisions are as follows:

1. **Inductance of armature reaction**
2. **Inductance due to space harmonics in the core length or differential leakage, which is subdivided into**
    - *a.* **Belt leakage inductance**
    - *b.* **Zigzag leakage inductance**
3. **Slot leakage inductance**
4. **End-winding inductance**

The first 3 divisions have been adequately treated by both Alger[1] and Kilgore,[2] who have derived formulas which apply accurately for most commercial machines. Formulas for the end-winding inductance have also been given, but all of them involve approximations which have not been adequately investigated.

It will be the purpose of this paper to develop formulas for calculating the end-winding self-inductance and leakage inductance on as sound a theoretical basis as possible and to obtain a direct experimental check of the resulting formulas for the single-phase, static case. The formulas for the 3-phase case will also be derived, but no experimental check will be given at this time.

Historical Review

Doherty and Shirley[3] were the first to develop formulas for the calculation of the armature inductance of salient-pole synchronous machines which held for a wide range of machines. Later Doherty and Nickle[4] introduced the concept of resolving the armature magnetomotive force wave into its rotating space harmonic components; and with the aid of Blondel's[5] concept of resolving such harmonics into components along the direct and quadrature axes, they developed formulas for the inductance of armature reaction and for the differential leakage inductance. They also proposed new and precise definitions for the inductances of armature reaction and the armature leakage inductance. Following the basic ideas developed in this paper Park and Robertson[6] proposed to standardize the definitions of the various types of inductances of synchronous machines, including the transient and subtransient inductances, and described methods of measuring them. At about the same time Wieseman[7] applied the technique of field plotting to salient-pole machines, which allowed an accurate determination of the constants necessary to calculate the inductances of armature reaction. With this basis Alger[1] developed more accurate formulas for armature inductance, and introduced the belt leakage and zigzag leakage inductance terms as used by Adams[8] in his treatment of induction machines. Later Kilgore[2] published a paper wherein he developed formulas for calculating armature inductance. He used essentially the same definitions as Alger, but his results were given in a slightly different form, and he gave formulas for calculating the transient inductances, and proposed the use of a saturation factor.

Theoretical Development

The approach which will be employed in the solution of this problem follows the same general scheme as that used by Doherty and Nickle[4] in calculating the inductance of the armature in the core length. That is, the magnetomotive force will be resolved into space harmonics, and the corresponding flux density wave will be found. The linkages will be determined with the aid of the equation of the flux density wave, from which the inductances will be found. The problem in this case differs from the core length solution in that the magnetic circuit is composed of air, and the magnetic field is 3-dimensional.

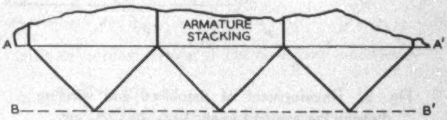

Fig. 1. Development of simplified end winding

Since writing this paper attention has been called to "Potentialfelder der Electrotecnik" (a book), F. Ollendorf, Julius Springer, Berlin, wherein a similar approach is made to this problem, but the solution obtained is not so complete in detail or results.

As in the method used by Doherty and Nickle,[4] it will be assumed initially that the conductors are concentrated and have zero cross-sectional area. It will also be assumed that the end-winding coils are V-shaped. Then the end-winding will have been simplified to the winding shown in figure 1. It will also be assumed that the end-winding conductors lie in a plane which is the plane of the development of the armature surface.

The end-winding region is the region enclosed by the 2 planes *AA′* and *BB′* as shown in figure 1, which cut the

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[1] For all numbered references see list at end of paper.

plane of the end-winding coils at right angles. The plane AA' passes through the end of the armature core; thus, it is the boundary formed by the iron of the armature and field. The plane BB' passes through the apices of the V-shaped end-winding coils.

In order to investigate the field in this region it is necessary to make some assumptions regarding the character of those boundaries. The iron of the armature core which forms the boundary AA' will contain eddy current paths, and the flux entering it from the end-winding region must enter at approximately right angles to these eddy current paths; therefore the iron will act somewhat as a magnetic shield. In view of this fact the component of flux which is normal to the end surface of the armature core will be neglected, and the lines of flux will be assumed to be parallel to the end of the armature core at this boundary. The same boundary condition will be obtained with the configuration shown in figure 2 where a second V-shaped coil is substituted for the armature core.

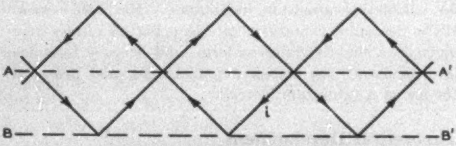


Fig. 2. Showing substitution of a second V-shaped conductor for the armature stacking

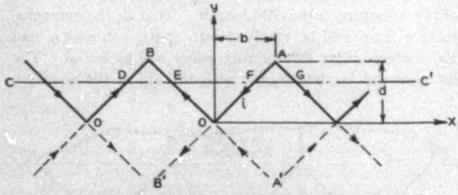


Fig. 3. Development of simplified end winding showing the assumed image OA′ of OA, etc.

The boundary condition at the plane BB' will be approximated by assuming that the end-winding conductors are produced as shown in figure 3; that is, OA is produced as OB', etc. This assumption is made primarily to simplify the solution. It will introduce an error proportional to the coupling between coils OAB and $OA'B'$ which will be discussed later.

The field in the end-winding region is symmetrical about the plane of the coil, and the problem is more easily treated by considering only the field on one side of the plane of the end-winding conductors. Because of this symmetry it is obvious that one-half of the total magnetomotive force is effective for either side of the plane of the conductors.

In obtaining a solution it is desirable to make the following simplifying assumptions and apply corrections later. These assumptions are:

1. That the end winding can be approximated by the V-shaped configuration as shown in figure 1.
2. That the conductors are of zero cross-sectional area.
3. That the end-winding conductors AO and BO as shown in figure 3 are produced as OB' and OA' and that these produced conductors carry the same current as the actual end-winding conductors.
4. That the component of flux normal to the end surface of the armature core is zero.
5. That the end-winding conductors lie in a plane which is the development of the cylindrical armature surface.
6. That the conductors in each phase group are concentrated.

Select a rectangular system of co-ordinates as shown in figures 3 and 4 with O, the apex of the coil, as the origin. Let x be measured in the peripheral direction, y in a direction parallel to the axis of the shaft, and z in the radial direction perpendicular to the plane of the development. All distances are measured in centimeters. The positive direction from the x co-ordinate is taken as the direction of rotation; the y co-ordinate is measured positive toward the armature core; and the positive direction of the z co-ordinate is taken in such a direction that a right-hand system of co-ordinates is formed. The dimensions b and d are measured in centimeters as illustrated in figure 3.

Select the magnetic reference potential as that existing along any line segment such as DE and FG of section C-C as shown in figure 3, or in other words, the plane bounded by $OBO'B'$. In traversing a flux line $efgh$ as shown in figure 4, a magnetomotive force drop of $4\pi ni$ is experienced, where each of the n conductors in the coil side E carries i abamperes of current. Since the field is symmetrical about the plane of $DEFG$, the magnetomotive force drop experienced in traversing efg is $2\pi ni$.

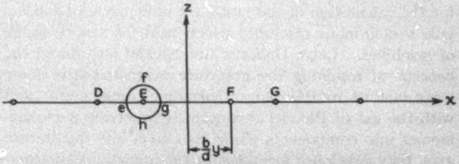


Fig. 4. Section of the end-winding region taken perpendicular to the developed plane of the end-winding conductors

If this magnetomotive force along a typical line formed by the intersection of the plane of section C-C and the x-y plane is plotted as ordinates against the distance along the line as abscissas, a curve as shown in figure 5 is obtained. The wave of the magnetomotive force along the x axis for several values of y is shown in order to demonstrate the variation along the y axis.

If $k = (P/D)(b/d)$ and $\gamma = (P/D)\,x$, where P is the number of poles and D is the diameter, then the equation of the rectangular magnetomotive force wave of figure 5 may be written as a Fourier series of the form

$$a = \sum \frac{A_q i_q}{m} \sin mky \cos m\gamma \tag{1}$$

where m is the order of the space harmonic, and takes the values $2jq + 1$; $j = 0, 1, 2, 3, \ldots$ and q is the number of phases. The values of A_q for single-phase and balanced 3-phase windings are

$$A_1 = 8n \tag{1A}$$

$$A_3 = 12n \tag{1B}$$

The next step is to determine the flux density wave corresponding to each of the components of the magnetomotive-force wave such as

$$a_m = \frac{A_q i_q}{m} \sin mky \cos m\gamma \tag{2}$$

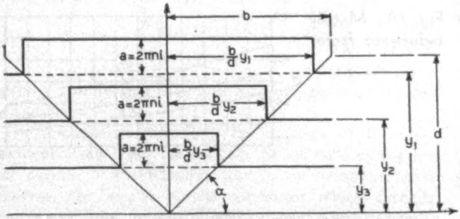


Fig. 5. Diagram showing magnetomotive force wave for various values of y

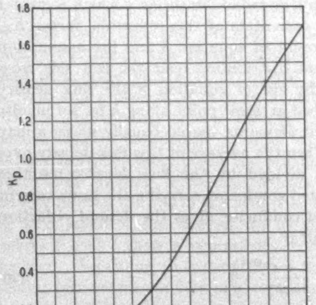


Fig. 5A. Pitch factor

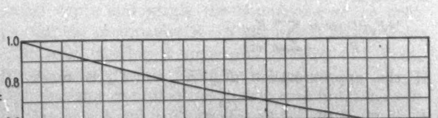
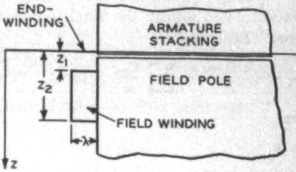


Fig. 5B. Radial distribution factor

Let B be the flux density in gausses at any point corresponding to the mth space harmonic of magnetomotive force, and let the subscripts x, y, and z indicate the components of B in the x, y, and z directions. For the region corresponding to positive values of z in which there is assumed to be no magnetic medium and no current carrying conductors, the equations

Fig. 6. View of armature and field taken perpendicular to the plane of end-winding coils



$$\nabla . B = 0 \tag{3}$$

and

$$\nabla \times B = 0 \tag{4}$$

must be satisfied subject to the boundary conditions

$$\left.\begin{aligned} B_x &= -\frac{\partial a_m}{\partial x} \quad (5)\\ B_y &= -\frac{\partial a_m}{\partial y} \quad (6)\end{aligned}\right\} \text{When } z = 0$$

and

$$B \rightarrow 0 \text{ as } z \rightarrow \infty \tag{7}$$

The desired solution for positive values of z is readily found by usual methods to be

$$B_z = B_m e^{-m\delta z} \sin mky \cos \frac{mpx}{D}, \tag{8}$$

where

$$\delta = \frac{P}{D} csc\alpha \quad (9) \quad \text{and} \quad B_m = \delta\, Aq\, iq \tag{10}$$

where α is the angle shown in figure 5.

The linkage ψ_m in abampere-henries per phase per pole for the V-shaped end-winding which has n conductors connected in series, is

$$\psi_m = n \int_0^d \int_{-\frac{b}{d}y}^{\frac{b}{d}y} \beta_m \, dx \, dy \times 10^{-9} \tag{11}$$

where $\beta_m = B_z$, when $z = 0$. Substitute the value of β_m from equation 8 into equation 11, and integrate to obtain

$$\psi_m = \frac{\pi n D^2 \tan \alpha}{2mP^2} B_m K_{pm} \times 10^{-9} \tag{12}$$

where K_{pm} is the pitch factor and is given by the equation

$$K_{pm} = p\left[1 - \frac{\sin mp\pi}{mp\pi}\right] \tag{13}$$

The inductance L_m in henries corresponding to these linkages is

$$L_m = \frac{\Psi_m}{i_q} \tag{14}$$

where i_q is the current in each of the n conductors of the end winding. Substitute the values of Ψ_m and i_q into equation 14 to obtain the total inductance per pole per phase. The result is

$$L = \frac{\pi F_q n^2 D \sec \alpha}{P} \sum \frac{K_{pm}}{m} \times 10^{-9} \tag{15}$$

where

$$F_1 = 8 \tag{16}$$

and $m = 1, 3, 5\ldots$, for the single-phase case, and

$$F_3 = 12 \tag{17}$$

and $m = 1, 5, 7\ldots$, for the 3-phase case.

This derivation is based on the 6 assumptions previously listed. It is now necessary to develop corrections for these assumptions. First, consider the assumption that the phases are concentrated. In general the phases consist of several groups of conductors, each group of which occupies a different slot, and these slots are spaced around the periphery of the armature. The space waves of magnetomotive force due to these coils are out of phase by an angle determined by the angle between slots and the order of the space harmonic. Therefore the resultant magnetomotive force is less than for the case of concentrated phases, and the reduction factor K_{dm} is applied to correct for this. Its value is given by the equation

$$K_{dm} = \frac{\sin m \frac{s\theta}{2}}{s \sin m \frac{\theta}{2}} \tag{18}$$

where θ is the angle measured in electrical radians between slots, and s is the number of slots per pole per phase. Also the electromotive forces induced in the armature conductors by the rotating space waves of flux will be out of phase for the same reason, hence the reduction factor K_{dm} must be applied again, or the total reduction factor is K_{dm}^2.

The factor, which applies to correct for the fact that the conductors have a dimension other than zero measured along the periphery of the armature, is equal to the ordinary distribution for a uniformly distributed phase which is distributed over the peripheral dimension c of the rotor surface. Thus,

$$K_{cm} = \frac{\sin \frac{mPc}{2D}}{\frac{mPc}{2D}} \tag{19}$$

The derivation of this relation is based on the assumption that the current is uniformly distributed over the cross section of the conductor.

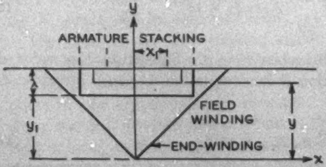
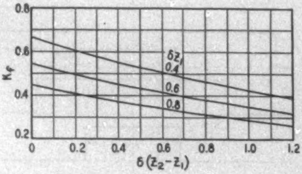


Fig. 7. Development of end winding showing the field winding

It should be noted at this point that the product K_{dm} K_{cm} is approximately equal to C_m, the distribution factor for a uniformly distributed winding, when spacing between the end-winding conductors is small as is usually the case. This is a good approximation particularly for the space fundamental.

Fig. 7A. Mutual inductance factor



The inductance is further reduced by the fact that the coil side has a depth or radial dimension h which is greater than zero. The derivation of this reduction factor K_{hm} is based on the result of equation 8 and the assumption of uniform current distribution over the coil side cross section. With the aid of equation 8 the flux density which is established at some point along h by an infinite number of current filaments spaced equally along h may be computed. Then the average of this flux density over the dimension h divided by the flux density resulting from a concentrated conductor carrying the same current as the distributed conductor gives the desired reduction factor. The result is

$$K_{hm} = \frac{2}{m\delta h}\left(1 - \frac{1 - e^{-m\delta h}}{m\delta h}\right) \tag{20}$$

If

$$K_m = K_{pm} K_{dm}^2 K_{cm}^2 K_{hm} \tag{21}$$

then the formula for the end-winding inductance may be written as

$$L = \frac{\pi F_q n^2 D \sec \alpha}{P} \sum \frac{K_m}{m} \tag{22}$$

If the approximation K_{dm} K_{cm} = C_m is made, then

$$K_m = K_{pm} C_m^2 K_{hm} = K_{pm} \frac{C_1^2}{m^2} K_{hm}' \tag{23}$$

and the end-winding inductance is

$$L = \frac{\pi F_q n^2 D \sec \alpha}{P} \sum \frac{K_{pm}\, C_1^2\, K_{hm}}{m^2} \tag{24}$$

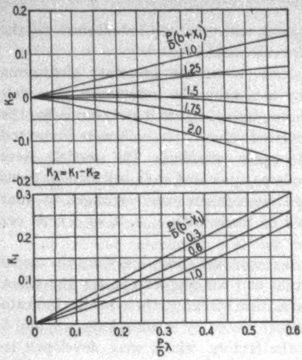


Fig. 7B. Mutual inductance factor

This series converges rapidly, and only the first term is necessary in computing for the usual case with the possible exception of the single-phase case where the third harmonic appears. In order to facilitate computation, curves of the factors K_{pm} and K_{hm} are given in figures 5*A* and 5*B*.

The assumption regarding the V shape of the end-winding coils is fairly close to the actual case except for that portion of the winding near to the armature core. However, the length of the conductor which extends straight out from the slot is usually small compared with the total length, and it seems that little error is introduced by this approximation.

The effect of the remaining assumptions has been investigated experimentally, and will be discussed later.

An important consideration, which has been completely ignored by previous writers, is the mutual linkage between the field coils and end winding. This is important; since, even though this mutual linkage may be a very small percentage of the total mutual linkage between the field and armature, it may be appreciable compared with the end-winding linkage thereby causing the end-winding *leakage* inductance to differ considerably from the total self-inductance of the end winding.

The field winding ordinarily extends an appreciable distance beyond the end of the field pole, hence this winding links some of the flux set up by the end winding. Figures 6 and 7 show a typical design for a salient-pole machine. According to assumption 4 none of the end-winding flux enters the field pole core, therefore, the only flux to be considered is that in the region occupied by the field winding which extends into the end-winding region.

The method to be employed in calculating this mutual linkage will be, first, to calculate the average component of flux perpendicular to the plane of the end winding over the radial depth and within the boundaries of the field coil by the use of equation 8. Next, it will be assumed that the field winding is uniformly distributed. Then the mutual linkage will be found by integration.

Select the same co-ordinate system as used in the derivation of equation 8 and as illustrated in figures 6 and 7.

Let the dimensions z_1, z_2, x_1, and λ be measured in centimeters as shown in the diagram. Consider the case where the pole axis coincides with the phase axis, and the resulting mutual linkage will be the maximum value. The average of B_z from z_1 to z_2 as found from equation 8 is given by

$$B_z = B_m K_{fm} K_{dm} K_{cm} \sin mky \cos \frac{mPx}{D} \tag{25}$$

where

$$K_{fm} = \frac{1 - e^{-m\delta h}}{m\,\delta\,h} \; \frac{[1 - e^{-m\delta(z_2 - z_1)}]e^{-m\delta z_1}}{m\delta(z_2 - z_1)} \tag{26}$$

The corresponding linkage is found by integration. Thus the linkage Ψ_m of the field coil due to the mth harmonic of the flux density wave set up by the field of the end winding is

$$\psi_m = \frac{D^2 n_f B_m K_{fm} K_{dm} K_{cm} K_{\lambda m} \times 10^{-8}}{m^3 P^2} \tag{27}$$

where n_f is the number of turns per field pole, and

$$K_{\lambda m} = \frac{\sin \frac{mP}{D}(b - x_1)}{1 + \frac{b}{d}} + \frac{\sin \frac{mP}{D}(b + x_1)}{1 - \frac{b}{d}} + \frac{\cos \frac{mP}{D}(b - x_1) - \cos \frac{mP}{D}\left[b - x_1 - \left(1 + \frac{b}{D}\right)\lambda\right]}{\left(1 + \frac{b}{d}\right)^2 \frac{mP}{D}\lambda} - \frac{\cos \frac{mP}{D}(b + x_1) - \cos \frac{mP}{D}\left[b + x_1 + \left(1 - \frac{b}{d}\right)\lambda\right]}{\left(1 - \frac{b}{d}\right)^2 \frac{mP}{D}\lambda} \tag{28}$$

The corresponding mutual inductance in henries per pole per phase for both ends of the end winding is

$$M_0 = \frac{2F_q n n_f D \csc\alpha}{P} \sum \frac{K_{fm} C_1 K_{\lambda m}}{m^2} \times 10^{-8} \tag{29}$$

This is the maximum value of mutual inductance. In general only the first term of the series is required. The factors K_{fm} and $K_{\lambda m}$ are rather complicated for computing purposes and they contain too many parameters to be given conveniently in the form of curves. However, if we neglect the effect of the term containing h in the expression for K_{fm} of equation 26, K_{fm} may be conveniently given in curve form as shown on figure 7*A*. Likewise a constant value of $b/d = 0.577$ ($\alpha = 60$ degrees) is assumed in plotting the curves for $K_{\lambda m}$ as shown in figure 7*B*.

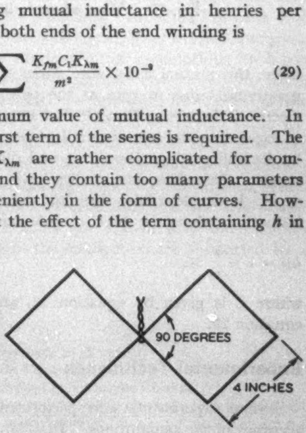


Fig. 8. Sketch showing diamond-shaped coils used in mutual inductance measurement

For a machine with a "sine wave winding"; that is, a machine which eliminates all effect on the terminal voltage of space harmonics of flux and magnetomotive

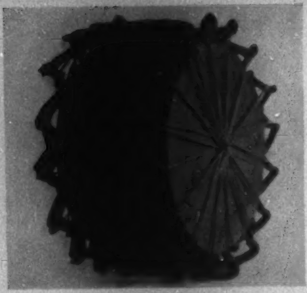


Fig. 9. End-winding model

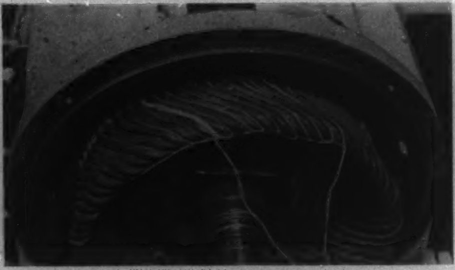


Fig. 10. View of exploring coils

force, this mutual inductance varies sinusoidally from its maximum value to zero as the pole moves through 90 electrical degrees. Blondel[5] first introduced the concept of expressing the armature inductance of such a machine by its values along the direct and quadrature axes, and most of the subsequent studies have employed this concept. It is desirable then to write the end-winding inductance along the direct or pole axis as

$$L_{1d} = L - \frac{n}{n_f} M_0 \tag{30}$$

where L is given by equation 22, and M_0 is given by equation 29.

Experimental Techniques

Several experiments were performed to determine the accuracy of the assumptions. In so far as seemed feasible, the experiments were so arranged that each assumption was checked separately.

In order to determine the order of magnitude of the error introduced by the assumption that the end-winding conductors were produced as shown in figure 3, the mutual inductance of 2 diamond-shaped coils as shown in figure 8 was measured. With the 2 coils connected in series, the inductance differed by 1.5 per cent from the sum of the 2 self-inductances. The mutual inductance will of course vary with the shape and size of the coils, but its magnitude is negligible compared with the self-inductance, so the assumption appears reasonable.

An experimental check on the accuracy of formula 22 was obtained by measuring the inductance of models as shown in the photograph of figure 9 and comparing the result with the calculated value. The coils were connected as a single-phase 4-pole winding. The models were equipped with 4 coils per pole and each coil had 20 turns in series. The coil connections were arranged so that measurements could be made with 1, 2, 3, or 4 coils per pole.

This agreement is reasonably good; and since the model duplicated the actual end winding except for the effect of the iron in the armature stacking, these results indicate that the total error introduced by assumptions 1, 3, and 5 and the errors in the factors, which were developed to correct for assumptions 2 and 6, as previously listed is approximately ± 3 per cent.

The next experimental check consisted in measuring the inductance of the end winding of an actual machine. The tests were made on a 15-horsepower 220-volt 1,800-rpm 60-cycle 4-pole 3-phase salient-pole synchronous motor. The armature winding was reconnected single-phase.

Exploring coils were used to measure the inductance. They were placed on the end winding as shown in figure 10 with a single turn of the exploring coil around each end-winding coil of a phase belt per pole. A 60-cycle voltage approximately sinusoidal in wave shape, was impressed on the armature circuit through an ammeter. The exploring coils were connected in series and the terminals were brought out to the input of a calibrated amplifier and voltmeter. The end-winding inductance was measured with the field axis and quadrature axis coinciding and with the field axis and the direct axis coinciding. Thus measurements were obtained for the conditions of maximum and minimum effect of the iron of the field stacking. The variation was found to be ±3.75 per cent from the average value.

The same arrangement was used in the measurement of the mutual inductance. In this case the field was

Table I—Comparison of Calculated and Measured Values of Inductance of the Models as Shown in Figure 9

Coils per Pole	L in Millihenries		Per Cent Error
	Calculated	Measured	
Model No. 1			
4	3.55	3.48	2.0
3	2.83	2.79	1.4
2	1.76	1.73	1.7
1	0.685	0.670	2.2
Coil pitch = 1.0, single-phase, 4-pole, D = 31 centimeters, b = 12.2 centimeters, d = 12.1 centimeters, c = 1.34 centimeters, h = 1.14 centimeters.			
Model No. 2			
4	2.98	3.02	1.3
3	2.34	2.44	2.9
2	1.49	1.52	2.0
1	0.635	0.630	1.0
Coil pitch = 0.75, single-phase, 4-pole, D = 44 centimeters, b = 12.95 centimeters, d = 11.35 centimeters, c = 1.34 centimeters, h = 1.14 centimeters.			

excited with a known current, while the machine was rotated at normal speed, and the voltage induced in the exploring coils was measured. Then

$$M_0 = \frac{E}{\omega I} \tag{32}$$

where E is the maximum value of the exploring coil voltage in volts, I is field current in amperes, and ω is the angular velocity in electrical radians per second.

A tabulation of the values of M_o and L_{ld} as determined from test and calculation is shown in table II along with the value end-winding leakage as calculated from the formula given by Alger.[1]

Conclusions

Let us consider now the effect of the primary assumptions previously tabulated. Accurate corrections have been developed for assumptions 2 and 6, and the probable error introduced by them is negligible.

The error introduced by assumption 3, regarding the continuation of the end-winding conductors beyond the apex of the V-shaped conductors, was determined by the measurement of the mutual inductance of 2 diamond-shaped coils. The error due to this assumption is approximately 1.5 per cent.

The errors introduced by assumptions 1 and 5 were evident in the measurement of the inductance of the end-winding model. The error due to assumption 3 was also included here, and the comparison of the calculated and measured value of inductance indicates an error of approximately ± 3 per cent.

The assumption that the component of the flux normal to the plane of the end of the armature core is zero is equivalent to assuming that none of the flux from the end-winding field enters the armature core. Since the ultimate aim of this study is to compute the end-winding *leakage* inductance, suppose that we assume instead that only the end-winding *leakage* field is unaffected by the iron of the armature stacking, and review the theoretical development on the basis of this assumption instead of the assumption that none of the flux from the end-winding field enters the armature core.

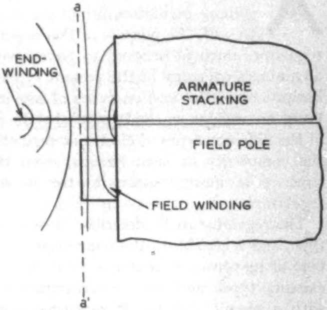
Physically the meaning of this assumption is apparent from a survey of the 2-dimensional sketch shown in figure 11. If there were no iron in the armature core the flux line at the boundary of the armature stacking would be vertical. Because of the iron the flux lines near the boundary are distorted as shown, but as the distance from the boundary increases the distortion due to the iron decreases, and this distortion of the field is apparently small beyond the boundary of the field pole winding; that is, the distortion is small in the region of the end-winding *leakage* field. It follows that this assumption is less radical than the assumption initially made, and only the simpler assumption is involved in the final result.

Table II—Winding Data; 18 Slots per Pole, 4 Turns in Series per Slot

	M_0— Milli-henries	Error—Per Cent	L—Milli-henries	Error—Per Cent	L_{ld}— Milli-henries	Error—Per Cent
Test value	3.81		0.892		0.460	
Calculated value	2.70	29.1	0.774	13.2	0.468	1.8
Calculated value from Alger's formula					0.469	

$P = 4$, $D = 29.0$ centimeters, $b = 6.93$ centimeters, $d = 8.13$ centimeters, $h = 1.10$ centimeters, $p = 0.61$, $n_f = 635$ turns per pole, $x_1 = 3.81$ centimeters, $= 3.81$ centimeters, $z_1 = 2.54$ centimters, $z_2 = 5.72$ centimeters.

Fig. 11. Sketch of end-winding field in a plane through the shaft axis and perpendicular to the plane of the end-winding coil



It is believed that equation 30 is a step nearer to an accurate formula for the end-winding leakage inductance than any previously published. An effort has been made to indicate the nature and consequence of the assumptions involved and the effects of these assumptions have been investigated from an experimental viewpoint. An important part of the result is the expression for the flux density given by equation 8. This equation should serve as a basis for studying the effects of iron in the end-winding region. For example, the analysis may be extended to calculate the end-winding inductance of turbine generators where the rotor extends well into the end-winding region and to calculate the end-winding inductance of d-c machines where the conductors are supported by an iron ring.

Nomenclature

a = magnetomotive force in gilberts
α = angle shown in Figure 5
A = constant as defined by equations $1A$ and $1B$
B = vector flux density in gausses corresponding the mth space harmonic of magnetomotive force as a function of the space co-ordinates, and the subscripts x, y, and z indicate the components of B in the x, y, and z directions
β = value of B when $z = 0$
b, d = end-winding dimensions measured in centimeters as shown in figure 3
C = reduction factor for a winding which is uniformly distributed over the phase belt
c = peripheral dimension in centimeters of the conductors
D = diameter of armature winding in centimeters
$\delta = \frac{P}{D}\sqrt{\left(\frac{b}{d}\right)^2 + 1}$

(*Concluded on pages 475–5*)

An Alternator-Voltage Regulator Utilizing a Nonlinear Circuit

By HARRY W. MAYNE

ALTHOUGH several different types of alternator-voltage regulators are in successful operation at present, the purpose of this paper is to describe a regulator which is believed to have several outstanding advantages over any of the present types. The inherent limitations of the various types of moving-contact regulators are well known, and a perusal of the circuit diagrams[1] of the different types of electronic regulators will indicate the complexity of such circuits, even though they are superior in most respects to the moving-contact-type regulators.

The regulator to be described here is of the electronic type, and is capable of the same degree of accuracy as the best of its type. It promises even faster operation than existing types and these characteristics are obtainable with a circuit utilizing 2 mercury-vapor control tubes combined with a small inductance, capacitance, and resistance.

Nonlinear Circuits

The eccentricities of circuits containing capacitance and saturable core inductance have long been known to engineers. The particular phenomenon which first attracted attention was the so-called inversion or instability of the neutral of a 3-wire star-connected bank of transformers feeding a highly capacitive transmission line. Considerable material[2] was written on the peculiarities obtained, but it was not until 1931 that publications discussing simple single-phase circuits appeared.[3] Only the simple series circuit shown in figure 1 will be discussed. In figure 2 we have the effective volt-ampere characteristics of the circuit for various values of the resistance. From these curves we see that as the resistance is decreased, the slope of the curve increases so that it is possible to obtain a very large change in the effective value of the current with a negligible change in the effective value of the impressed voltage. Of course further reduction of the resistance produces a characteristic which is double-valued in current over a certain range of voltage, but these properties are of no utility in this particular application except as a limiting case.

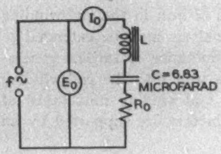


Fig. 1. Nonlinear series circuit

R_0 represents total d-c resistance of circuit

Because of the presence of the iron-cored coil, the wave form of the current in such a circuit is not sinusoidal, and is subject to considerable change as the effective value changes. Figure 3 is an enlarged drawing of superimposed oscillograms which illustrates the variation for the particular circuit used. Referring to figure 3, I_1 represents an effective value of 0.21 ampere, and the voltage required was 110 volts. When the voltage was increased to 111 volts, I_2, with an effective value of 0.43 ampere was obtained. The resistance in the circuit was 125 ohms, and the frequency 60 cycles per second. From the drawing we see that when the lower value of current is flowing, the crossing points of the current wave lag those of the voltage wave by approximately 20 degrees, and the peak current of 0.414 ampere occurs at 139 degrees. When the impressed voltage is increased from 110 to 111 volts effective value, or less than 1 per cent, the peak current increases to 0.908 amperes, or more than 100 per cent. In addition the wave is shifted so that the crossing points of the current wave are in the phase with those of the voltage wave. The peak current is also shifted by the same angle, approximately 20 degrees.

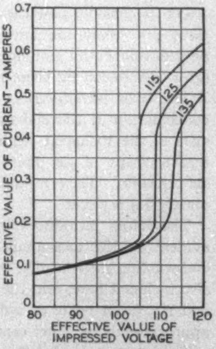


Fig. 2. Effective volt-ampere characteristics for circuit of figure 1 at 60 cycles per second

Numbers on curves are values of R_0 in ohms

Application

With these general properties of the circuit in mind, the circuit shown in figure 4 was developed and tested. The alternator used was a 7.5-kva 60-cycle machine synchronously driven from a source having a frequency variation of ±0.3 cycle in 60. With a 7.5-kva load at

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[1] For all numbered references see list at end of paper.

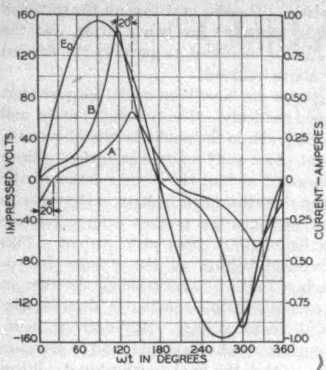

Fig. 3. Variation of wave form of current in nonlinear circuit with impressed voltage

A—I_1 = 0.21 ampere, E_1 = 110 volts, effective values

B—I_2 = 0.43 ampere E_2 = 111 volts, effective values

R_0 = 125 ohms, frequency = 60 cycles

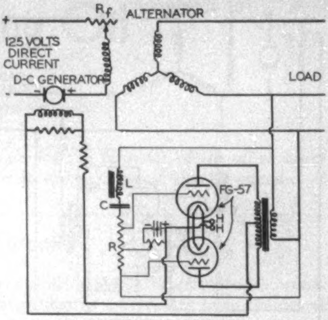

Fig. 4. Circuit diagram of counter-electromotive-force regulator using nonlinear-circuit control

0.85 power factor, the alternator regulation was 12 per cent and a 25 per cent decrease in field current was necessary to maintain normal voltage from full load to no load. The d-c end of a small a-c to d-c motor-generator set was used as a counter-electromotive-force generator in the alternator field circuit, and the drive was floated across the line to maintain constant speed. Type *FG*-57 thyratrons were used as grid-controlled rectifiers supplying the counter-electromotive-force field. As these tubes are negative control tubes, it is necessary to use a d-c

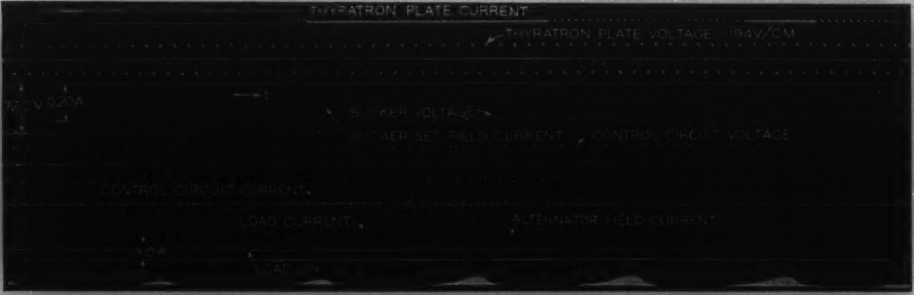

Fig. 5a. Operation of regulator of figure 4 when load is applied

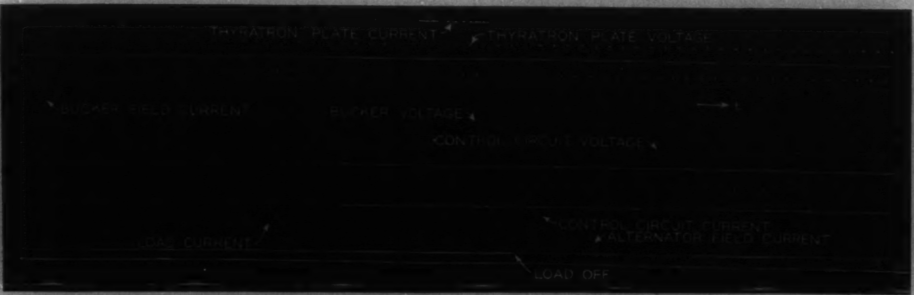

Fig. 5b. Operation of regulator of figure 4 when load is removed

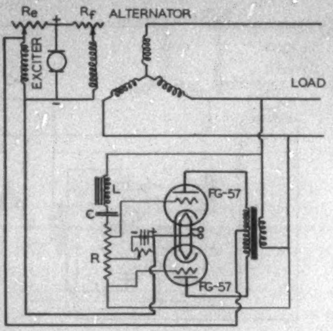

Fig. 6. Circuit diagram of nonlinear - circuit regulator operating on field of main exciter

grid bias in addition to the a-c component. The use of the proper type of positive-grid-control tube would dispense with this grid battery.

The following preliminary adjustments are necessary to put the regulator in operation. The nonlinear circuit is adjusted so its characteristic is very steep at normal voltage on the alternator. With full load on the machine the field excitation is increased until the alternator voltage is just below the sensitive portion of the nonlinear circuit characteristic. The d-c grid bias on the rectifiers is then adjusted so the tubes are barely firing, and the field excitation further increased to provide the desired reserve capacity above full load.

After these adjustments have been made, suppose that the load is dropped suddenly. The terminal voltage will rise, producing a large rise in the nonlinear-circuit current, with the attendant phase shift referred to earlier. Since the circuit is connected so that the phase relation of the grid voltage to the thyratron plate voltage is the same as shown in figure 3, both changes produce a large increase in the average value of the rectifier plate current. This increases the terminal voltage of the counter-electromotive-force machine, with a corresponding decrease in alternator field excitation, thus tending to decrease the abnormally high alternator voltage. Any decrease, however, will react on the control circuit and tend to decrease the current again, so that the final equilibrium condition for no-load will be at a slightly higher voltage than at full load. With the machines used a regulator sensitivity of ± 0.2 per cent was obtained. The frequency variation of the source increased the variation to ± 0.3 per cent. The operation of the regulator is illustrated by the oscillograms shown in figures 5*a* and 5*b*. These show the variations when full load is applied and removed respec-

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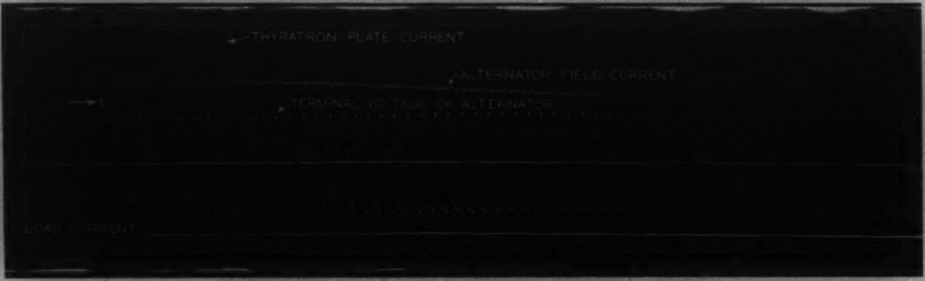

Fig. 7a. Operation of regulator of figure 6 when load is applied

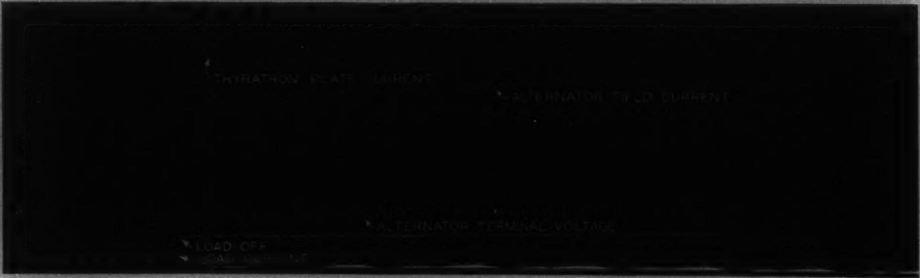

Fig. 7b. Operation of regulator of figure 6 when load is removed

Oxidation in Insulating Oil

By J. B. WHITEHEAD
FELLOW AIEE

F. E. MAURITZ
ENROLLED STUDENT AIEE

I. Introduction

IT is generally agreed that of the component parts of impregnated paper, the impregnating oil is most susceptible to deterioration. There is, however little definite knowledge of the processes leading to instability. Instablility manifests itself in changes in electrical properties. An increase in dielectric loss, if allowed to continue, ultimately leads to failure. Marked chemical changes often accompany these changes in electric properties, but whether or not the changes are caused by electrical stress, as related to the inherent chemical structure of the oil, or by residual impurities, as related to stress and structure, or by both jointly is as yet unknown. Obviously oxidation, with its generation of acids and consequent increase in chemical dissociation and electrical conductivity is a powerful cause of instability. Although careful provision is made for the elimination of oxygen in the manufacture of insulation, it is recognized that traces of oxygen must remain under all circumstances, and the determination of the degree of its activity as a cause of insulation instability becomes a matter of great importance.

To the electrical engineer, the electrical stability of an oil is measured not in terms of the specific chemical changes that are taking place, but in changes in its electrical properties, i.e., its conductivity, dielectric loss, power factor, or phase difference, dielectric constant and breakdown strength. Extensive studies of the variations of these quantities over the life of impregnated insulation have been made, and a highly developed technique is available. Characteristic changes in the electrical properties, through the life of the insulation, are often traceable to changes in conductivity and ionic content,[1] and there are other conspicuous evidences of chemical changes. But as stated, there is still great uncertainty as to the original cause of these changes and of their subsequent progress. Many studies have been made of the process of oxidation in mineral and in other oils as used for insulation. It is a highly complex process involving many end products, as is natural in view of the complexity of the oil molecule itself. However, while much information is now available as to the process of oxidation and its various end products, there is little available material correlating the oxidation of an oil with its electrical properties.

In this paper we report a series of studies of accelerated oxidation in a highly refined insulating oil as used in oil-filled cables, with particular reference to the correlation between oxidation and electrical properties. For certain of these properties there is a marked correlation. The tests have been made at higher temperatures than normal for insulation, in order to accelerate the complete program. There are definite indications, however, that reliable deductions may be made for the behavior of the oil at lower temperatures and in the presence of smaller amounts of oxygen.

II. Scope of Studies

The literature on oil oxidation often indicates erratic electrical correlation due to uncertainty as to the degree of the oxidation.[2] In studies of this character empirical methods have often been used,[3] as for example oxidation is measured by the number of hours of heating in air or oxygen. Obviously more accurate methods are necessary.

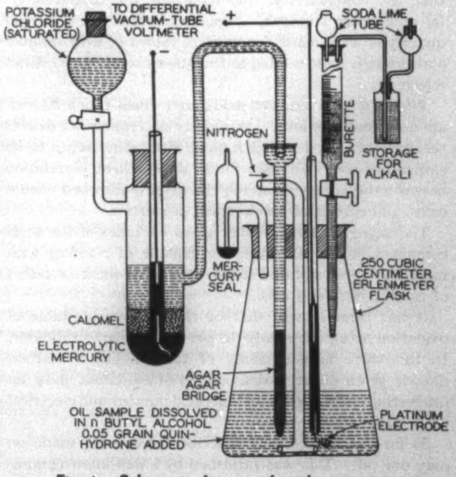
POTASSIUM CHLORIDE (SATURATED)
TO DIFFERENTIAL VACUUM-TUBE VOLTMETER
+
−
SODA LIME TUBE
BURETTE
STORAGE FOR ALKALI
NITROGEN
MER-CURY SEAL
250 CUBIC CENTIMETER ERLENMEYER FLASK
CALOMEL
ELECTROLYTIC MERCURY
AGAR AGAR BRIDGE
OIL SAMPLE DISSOLVED IN n BUTYL ALCOHOL 0.05 GRAIN QUIN-HYDRONE ADDED
PLATINUM ELECTRODE

Fig. 1. Schematic diagram of acidity apparatus

The chemical quantities here measured are as follows: (*a*) the amount of oxygen chemically absorbed, the rate of absorption, and the reaction constant *k*, at the 3 temperatures 120, 135, and 150 degrees; (*b*) the activation energy as deduced from the results under (*a*); (*c*) acid number; (*d*) saponification number; and (*e*) carbon dioxide evolved; all as related to the amount of oxygen absorbed.

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[1] For all numbered references see list at end of paper.

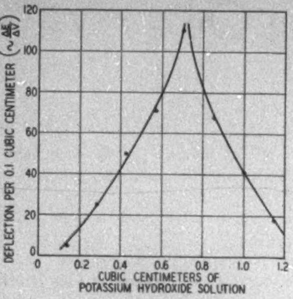


Fig. 2. Typical titration curve

The electrical quantities measured are: (*a*) power factor and a-c conductivity; (*b*) dielectric constant; (*c*) short-time d-c conductivity; (*d*) long-time d-c conductivity; (*e*) breakdown strength. Measurements of the electrical quantities were made for various values of acid number and through these related to the other chemical quantities referred to.

When an oil is oxidized acids are formed which dissociate and form new ions. An acidity determination defines the state of the oil in this respect without reference to its earlier history. We have found an excellent correlation between the acidity of an oil, the oxygen absorbed chemically, and certain of its electrical properties.

The saponification number gives an index of the acids combined in the oil which are capable of reacting with metals to form metallic soaps with consequent increases of conductivity and loss.

It has been shown[4] that of the gaseous products of oxidation of an oil, nearly 45 per cent is carbon dioxide. In this work measurements of the amount of carbon dioxide given off at various stages of oxidation show an interesting correlation with both acid number and electrical properties.

So far the studies here described have been made on only one oil. This was furnished by a well-known manufacturer and its properties are as follows:

Base	refined light oil
Specific gravity at 45 degrees centigrade	0.877
Flash point, degrees centigrade	149
Pour point, degrees centigrade	−29
Surface tension at 45 degrees centigrade	27
Viscosity, poises, at 45 degrees centigrade	0.133
Viscosity, poises, at 40 degrees centigrade	0.160
Breakdown volts	27,500

III. Experimental Method

OXYGEN CHEMICALLY ABSORBED

Twenty cubic centimeters of the oil were placed in a 50-cubic-centimeter bulb and degasified at less than 1 millimeter mercury pressure. The oil was then saturated with oxygen by shaking for 5 minutes in an atmosphere of oxygen at atmospheric pressure. The bulb was then connected to a mercury burette filled with oxygen and then placed in a thermostat which maintained a constant temperature to within 0.1 degree Centigrade. The oxygen above the oil was maintained at atmospheric pressure. The bulb was then mechanically connected to a shaking machine and shaken at a constant speed of approximately 300 cycles per minute. Burette readings were then recorded as function of the time. This process was repeated for the 3 different temperatures 120, 135, and 150 degrees Centigrade. The oxygen absorption-versus-time curve thus obtained, is a straight line over a long period. The slope of this line, expressed in terms of cubic centimeters of oxygen chemically absorbed per 100 grams of oil per hour, is the reaction constant, *k*. This constant permits the determination of the activation energy of the oil as described below.

DETERMINATION OF THE ACID NUMBER

The acid number was determined with the method described by Clarke, Wooten, and Kompton.[5] The apparatus consists essentially of a titration cell and a reservoir for the storage of alkali, an electrode system, and a differential vacuum tube voltmeter. A schematic diagram is shown in figure 1. A second tube voltmeter was used to determine the total voltage of the electrode system at any stage of titration. The base electrode is a saturated calomel half-cell which made contact with the solution to be titrated through an agar agar bridge. The chemicals used in the calomel half-cell were specially prepared, and its voltage was 0.558 volt. The indicator electrode consisted of a bright platinum wire dipping into the solution to be examined. This solution consisted of approximately 8 grams of degasified and dehydrated oil dissolved

Fig. 3. Charging current characteristics of undeteriorated oil

1,000 cycles per second
Series resistance—400,000 ohms
Sensitivity—0.0211 volt per centimeter
E—1,500 volts
Power factor—0.000634

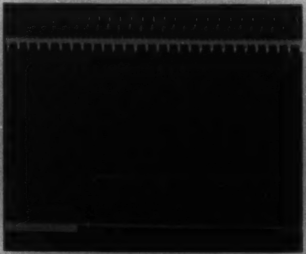
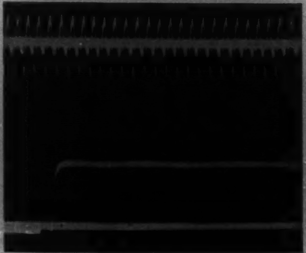


Fig. 4. Charging current characteristic of most deteriorated oil

1,000 cycles per second
Series resistance—25,000 ohms
Sensitivity—0.0228 volt per centimeter
E—1,500 volts
Power factor—0.01360



in 100 cubic centimeters of *n*-butyl alcohol to which 0.05 grams of quinhydrone had been added. All titrations were carried out in an atmosphere of nitrogen which served both to stir the solution and to exclude carbon dioxide which would lower the neutralizing value of the alkali. The technique of operation is as follows:

The differential voltmeter was first adjusted to read zero by varying a compensating resistor R_2. Known increments of alkali from the burette were added and corresponding deflections observed on a milliammeter. After every increment the differential voltmeter was compensated to zero milliammeter reading by adjusting R_2. These known equal increments of alkali were added up to, and after a maximum deflection was recorded. For accurate determinations the results are plotted as shown in figure 2, with deflection per 0.1 cubic centimeter as ordinates and total cubic centimeters of alkali added as abscissae. The maximum in this curve corresponds to the end point, that is the point where the slope of the voltage versus titer curve is a maximum. The apparatus as used here had a sensitivity for acid number better than 0.001.

Some observers report a double maximum in the curve of figure 2. This has been studied by Wooten and Reuhle[6] who show that it may appear when the alcoholic potassium hydroxide solution (titer) becomes deteriorated. Clear nonturbid solutions were used in this investigation and there was no occurrence of a second maximum. For the curve of figure 2, 0.715 cubic centimeter of 0.0387 *N* alcohol potassium hydroxide solution was necessary for neutralization of an 8.39-gram oil sample. Titration of the blank solvent had shown that less than 0.01 cubic centimeter of 0.0387 *N* alcohol potassium hydroxide was necessary for neutralization. The molecular weight of potassium hydroxide is 56.11. The acid number is then computed as follows:

$$\text{Acid number} = \frac{(0.715 - 0) \times 0.0387 \times 56.11}{8.39}$$

$$= 0.185 \text{ milligrams potassium hydroxide per gram of oil}$$

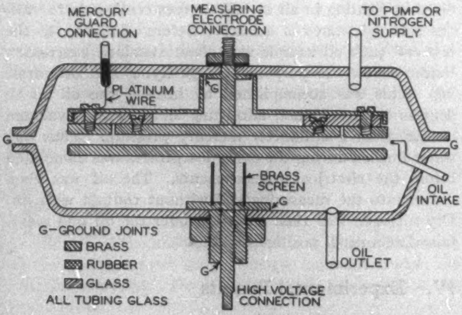


Fig. 5. Oil cell for electrical measurements

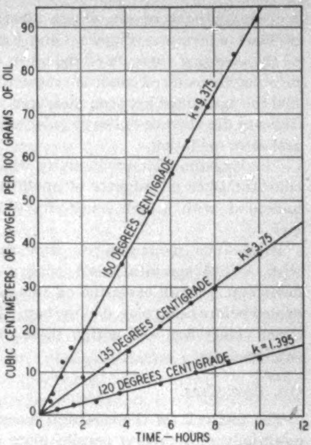


Fig. 6. Oxygen absorption versus time

Saponification Number

When an oil is oxidized it may react with metals with which it is in contact to form metallic soaps of high conductivity which are usually soluble in the oil itself. A soap is defined as a metallic salt of a fatty acid. The saponification number is a measure of the amount of acids present capable of forming these soaps. Its determination consists essentially in the boiling of a known quantity of oil with a known quantity of potassium hydroxide. The excess potassium hydroxide not spent in neutralizing acids is then titrated with hydrochloric acid and serves as an index of the soaping value of the oil. The saponification number is expressed in terms of milligrams of potassium hydroxide per gram of oil. Determinations of saponification number in this work were made substantially in accordance with the specifications recommended by the American Society for Testing Materials.[7] Numbers observed were in the range 0 to 3.0 and duplicate determinations agreed within 0.1.

Carbon Dioxide Given Off

The amount of carbon dioxide formed during the oxidation process was measured at different stages of the measurement of oxygen absorption by bringing the gas above the oil in contact with a potassium hydroxide solution. The difference of burette readings before and after this operation gives the amount of carbon dioxide formed.

Electrical Measurements

The a-c quantities, power factor, a-c conductivity, dielectric constant, were measured on a shielded high sensitivity Schering bridge as described by Kouwenhoven and Baños.[8] The power factor sensitivity is 0.000006. Measurements were made at 60 cycles supplied from a generator having a pure sine wave. In all these measurements 2 determinations with exchange of the positions of the standard and the oil cells were made.

The a-c conductivity was computed from the dielectric loss and found to be in close agreement with direct measurements of the short time or initial conductivity as measured with the amplifier oscillograph.[9,10] Whitehead[11] has shown that the initial d-c conductivity and the a-c conductivity of an oil are identical when no polar element is present. Figures 3 and 4 give the oscillograms of the charging currents of the oil in its initial and in its most highly oxidized condition respectively. These curves and the agreement between measured and computed losses indicate the absence of heavy polar aggregates both before and after oxidation.

The long-time d-c conductivity which is approximately constant after 20 minutes of application of voltage was measured with a high sensitivity d'Arsonval galvanometer.

Breakdown measurements were made in accordance with ASTM specifications[12] using a commercial breakdown cup. In all cases the oil was degasified and dehydrated before being placed in the cup. The spread of breakdown values was well within those called for by ASTM specifications.

OIL TEST CELL

The test cell for the electrical measurements consisted essentially of a circular parallel plate capacitor equipped with guard rings as indicated in figure 5. The electrodes were of polished brass. The measuring electrode had a diameter of 13.0 centimeters surrounded by a guard ring 2.54 centimeters wide, with an air gap of 0.16 centimeters. Glass insulation and screening is indicated in figure 5. The capacitance of the cell when empty was 77 micromicrofarads and when full approximately 177 micromicrofarads. The measurements were made at 60 cycles and a stress of 25 volts per mil with electrode separation of 0.152 centimeter.

The electrodes were supported one each in 2 similar glass containers, one of which was inverted, placed on the other with ground surfaces of contact as indicated. The lower container supported the high voltage electrode with a cylindrical screw guard rigidly attached. The top member was coated with tin foil and maintained at guard potential to prevent leakage currents entering the measuring circuit. The test cell held approximately 1,000 cubic centimeters of oil and was so connected as to permit vacuum intake during measurements. The whole cell was enclosed in a thermally insulated box with temperature controlled by thermostat to within 0.2 degrees centigrade and with provision for constant air circulation within the box.

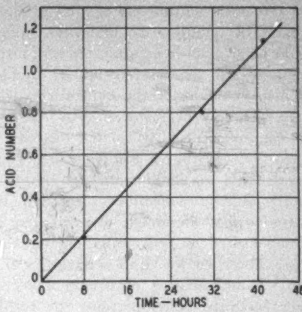


Fig. 8. Acid number versus time

Oxidizing temperature—150 degrees centigrade

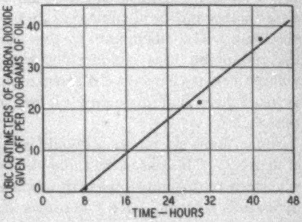


Fig. 9. Carbon dioxide given off versus time

Oxidizing temperature—150 degrees centigrade

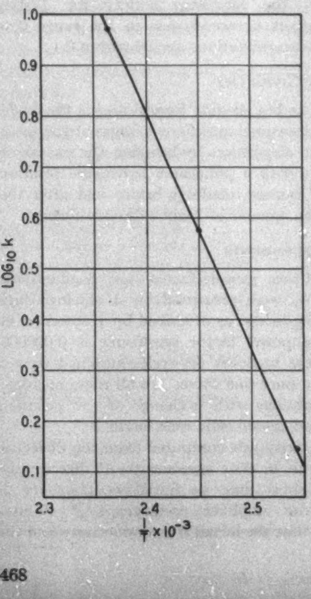


Fig. 7. Log_{10} k versus 1/T

Q = 20,700 calories per mol

The oils used in the electrical measurements were oxidized by heating in air at 125 degrees centigrade to various selected values of acidity. Before admission to the test cell each oil sample was given standard evacuation treatment for the purpose of degasifying and dehydrating. This was accomplished by heating the oil to 80 degrees centigrade and admitting slowly into a vacuum of less than 1 millimeter mercury pressure. Thus any water formed during the oxidation process was eliminated before the electrical measurements. The oil was then drawn into the measuring cell without contact with air. Dry nitrogen was then admitted over the oil and maintained at a small positive pressure.

IV. Experimental Results

The principal experimental results are shown in figures 3 and 4, and figures 6 to 23.

CHEMICAL PROPERTIES

Figure 6 shows the relation between oxygen chemically absorbed and time at each of the 3 temperatures 120, 135, and 150 degrees Centigrade. The ordinates are cubic centimeters of oxygen per 100 grams of oil, and the abscissae, the time in hours. The slope of each of these straight lines is the reaction constant *k* and is expressed arbitrarily in terms of cubic centimeters of oxygen per 100 grams of oil per hour. It will be noted that there is a strictly linear relationship with definite value of k at each temperature. Beginning at zero on the time scale, there is thus no induction period or lagging time of the oxygen reaction. Such lag is often noted at lower temperatures. Thus in the present case lags of 12, 27, and 49 hours were noted at the temperatures 100, 90, and 80 degrees, respectively.

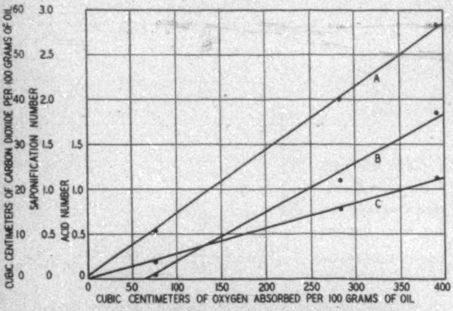


Fig. 10. Acid number, saponification number, and carbon dioxide given off versus oxygen absorption

Oxidizing temperature—150 degrees centigrade
A—Saponification number
B—Carbon dioxide
C—Acid number

It is necessary for a molecule to be activated before chemical reaction can begin. For this a minimum quantity of energy is necessary. In the present case this energy, in the form of heat, was found to be constant over the range studied. Thus a determination of the amount of this heat appears to be a good criterion as to the susceptibility of the oil to the oxygen reaction. The activation energy Q may be determined from the data of figure 6 by the use of the Arrhenius equation:

$$\frac{d \log k}{dT} = \frac{Q}{RT^2}$$

in which T is the absolute temperature, Q the activation energy in calories per mol, R the gas constant, and k, the reaction constant. On integration of the equation we have:

$$\log_{10} k = c_1 - \frac{Q}{4.58} \times \frac{1}{T}$$

whence Q may be determined graphically by plotting $\log_{10} k$ as function of $1/T$, as shown in figure 7. While only 3 points are available for this curve, corresponding to the 3 temperatures studied, it is seen that they lie accurately on a straight line indicating a constant value of 20,700 calories per mol for Q within this range, with no evidence of a change in slope such as might be caused by molecular disruption or cracking as sometimes proposed.[13] There is clear suggestion here that the activation energy of this oil is constant, at least up to the temperature of 150 degrees.

Figure 8 shows a linear relationship between acid number and time in hours of heating at 150 degrees centigrade, and figure 9 shows a linear relation between the carbon dioxide given off and time of oxidizing at 150 degrees centigrade. In figure 10 the observations of acid number, carbon dioxide, and saponification number are shown together as related to the amount of oxygen absorbed per 100 grams of oil. In obtaining these data 3 samples were drawn for acidity determinations at 8, 30 and 41.8 hours respectively of the continuous oxidation run. The saponification data were taken on a separate run with simultaneous observation of acid number.

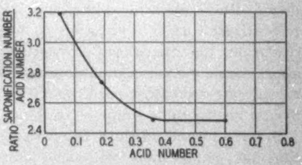
In figure 11 the ratio of saponification number to acid number is plotted as function of acid number. It is seen that in the initial stages of oxidation, there are relatively few free acid ions as compared with the acids combined in the oil. On further oxidation the ratio of these 2 concentrations approaches a constant value.

Electrical Properties

The correlation between chemical and electrical properties is shown in table I, from which the following curves have been plotted.

Figure 12 indicates a definitely linear relationship between power factor as measured at 40 degrees Centigrade and the acid number. Figure 13 shows a similar relation between power factor and saponification number.

Fig. 11. Ratio (saponification number/acid number) versus acid number



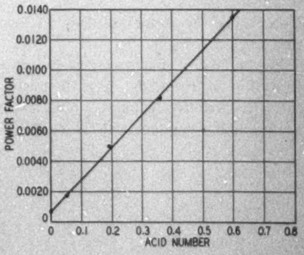


Fig. 12. Power factor versus acid number at 40 degrees centigrade

Figures 14 and 15 show the variation of dielectric constant with acid number and saponification number, respectively. As seen, these curves are slightly concave upward and indicate an over-all increase of nearly 5 per cent in

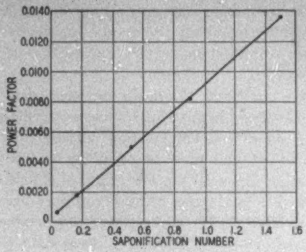
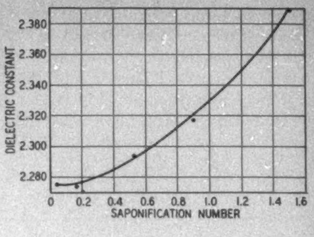


Fig. 13. Power factor versus saponification number at 40 degree centigrade

Fig. 15. Dielectric constant versus saponification number at 40 degrees centigrade



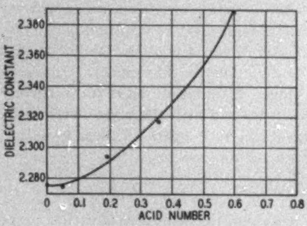
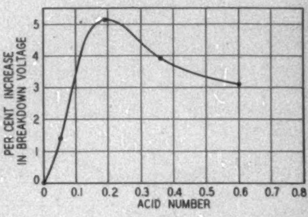


Fig. 14. Dielectric constant versus acid number at 40 degrees centigrade

Fig. 16. Per cent increase in breakdown voltage versus acid number

Initial breakdown voltage 27,500 volts



dielectric constant over the range 0.0 to 0.6 for acid number.

Figures 16 and 17 show the relationship between breakdown voltage and acid number and saponification number, respectively. It is interesting to note that on initial oxidation, the breakdown strength of the oil increased approximately 5 per cent, and upon further oxidation only a moderate decrease toward the initial value is indicated over a considerable range of oxidation.

Figures 18 and 19 show the variation of final or long-time d-c conductivity with acid number and saponification number, respectively. Final conductivity is seen to vary from 0.2×10^{-15} to 154×10^{-15} mhos per centimeter over the range studied, an increase of some 750 times.

Figure 18 also shows a curve of computed final conductivity due to free acids. For the purpose of computation, the oil is assumed to have one representative acid having a molecular weight of 150 (Herzfeld[14]) and 2 replaceable hydrogen atoms per molecule. The neutralizing process with potassium hydroxide provides a relation between acid number and concentration of acids in grams per liter of oil. Then using the dissociation constant given by Gemant[15] and the method of the latter, taking due account of viscosity, the value of the final conductivity may be computed. As shown in figure 18 the value so found is of the order of $^1/_{12}$ of the measured conductivity which would seem to suggest some other cause of conductivity than the presence of acid ions. While the figure of 150 for the molecular weight proposed by Herzfeld is quite high the conductivity varies only inversely as the square root of the molecular weight and a substantial reduction in the figure used would still leave a large part of the conductivity unaccounted for.

Figures 20 and 21 show the ratio of the a-c or initial conductivity to the final conductivity as function of acid number and saponification number, respectively. These curves are especially interesting as showing the influence of the oxidation products on the conductivity. For the oil in its initial state, with the acid and saponification numbers practically zero, the ratio of a-c to final conduc-

Table I—Electrical Results

Acid Number*	Saponification Number*	A-C Power Factor	Dielectric Constant	λ_{ac}— Mhos per Centimeter $\times 10^{-14}$	λ_i— Mhos per Centimeter $\times 10^{-14}$	λ_f— Mhos per Centimeter $\times 10^{-14}$	Ratio $\frac{\lambda_{ac}}{\lambda_f}$	Dielectric Loss— Watts per Centimeter $\times 10^{-9}$	Breakdown Voltage at Room Temperature
$\cong 0$	<0.05	0.00065	2.2755	4.93	4.81	0.02	247	11.1	27,500
0.052	0.166	0.00175	2.2745	13.3	12.9	1.05	12.65	29.9	27,875
0.19	0.52	0.00500	2.2940	38.3	38.0	4.54	8.45	86.2	28,900
0.36	0.90	0.00820	2.3170	63.4	62.9	8.8	7.20	142.4	28,575
0.60	1.50	0.01360	2.3890	108.5	108.7	15.4	7.05	244.5	28,350

Dielectric loss computed at 1,500 volts.

* Expressed in milligrams of potassium hydroxide per gram of oil.

tivity is approximately 247. This ratio decreases rapidly with oxidation and seems to approach a final value. At an acid number of 0.605, the ratio is 7.05. This is in accord with the observations of Whitehead and coworkers[16] that increasing final conductivity is accompanied by a reduction in the value of this ratio.

In figures 22 and 23 the dielectric loss, as computed from the bridge measurement is plotted as function of acid number and saponification number, respectively. The losses were measured at 40 degrees centigrade, 60 cycles and a stress of 25 volts per mil. Values of a-c conductivity computed from the dielectric loss measurements and the initial or short time conductivity, as measured by the amplifier oscillograph were in close agreement, as shown in table I. The dielectric loss at constant stress varies in linear relation with the acid number following the corresponding variation of the power factor. The variation of dielectric constant with acid number, shown in figure 14 is too small in over-all value to cause an appreciable variation of the dielectric loss from that of its linear relation with acid number.

V. Discussion

The Oxidation Process

The linear relation between oxygen chemically absorbed and time, shown in figure 6 indicates that the products of oxidation in the range studied do not act as catalysts for further oxidation. Dornte[17] and Egerton[18] report a "self-acceleration" for certain oils, i.e., the products of initial reaction augment further reaction. There is no evidence of such action here.

At low oxidation temperatures there is an initial period at which there is negligible and unstable absorption of oxygen by the oil. The oil will absorb and then give off oxygen of varying quantities. The duration of this condition is called the "induction period" and its length decreases rapidly with temperature elevation. There is difference of opinion as to the cause of the induction period. Some hold that it is a property of oxidizability of the molecules, others that it is due to impurities in the oil which may act positively or negatively in retarding oxidation. The so-called antioxidants serve to prolong the induction period, whereas a catalyst such as copper shortens it. However, once the reaction begins, the oxygen absorption versus time curves appear to obey the same law, as shown here, and also by Egerton[18] in studies of the same oil (*a*) alone, (*b*) in the presence of copper, and (*c*) when containing an antioxidant. Similar conclusions are to be had from the work of Dornte.[17,19]

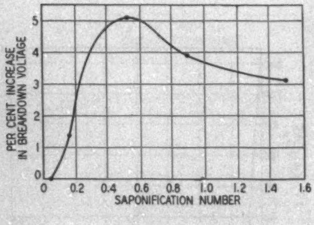


Fig. 17. Per cent increase in breakdown voltage versus saponification number

Initial breakdown voltage 27,500 volts

The linear relations shown in figure 10 indicate that at 150 degrees for the oil studied there is no induction period in the uniform rise of the values of acid number and saponification number with oxygen absorbed. There is, however, a lag or induction period for carbon dioxide evolved of about $6^1/_2$ hours. Uniform rises of both acid number and saponification number within this period indicate that the processes leading to the appearance of carbon dioxide also begin uniformly, so continue through the induction period, and on into the actual evolution of carbon dioxide. In other words, the process is continuous although it may not be immediately evident.

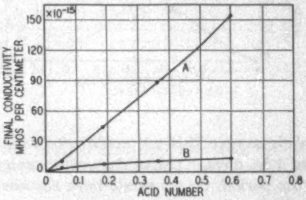


Fig. 18. Final conductivity versus acid number at 40 degrees centigrade

A—Measured
B—Computed conductivity due to free acids

The activation energy is constant over the range 120 to 150 degrees. A part of this energy is obviously expended in the hidden processes of the induction period of carbon dioxide. The $6^1/_2$ hours of this period measured at 150 degrees is presumably longer at 120 degrees, yet the activation energy is constant over this range. Thus it seems reasonable to conclude that the straight line relation of figure 7 (constant Q) may be extended to lower temperatures and that the activation energy is constant in the lower temperature range and at the value determined in the upper temperature range. The activation energy so determined thus appears as a definite measure of the rate of chemical absorption of oxygen or of oxidizability. A sharp change in the slope of the curve of figure 7 would indicate a critical temperature, marking a change in oxidation process. The existence of such a critical temperature at about 120 degrees is proposed by Gemant[13] and others. Karapetoff[20] finds no evidence of such critical temperatures in the work from American laboratories. Dornte[19] in experiments up to 185 degrees Centigrade finds no evidence of a "cracking temperature." Oxidation in insulating oils has long been recognized as a chain process. Dornte [17,19] studying 2 groups of oils found different laws for the 2 groups, but noted that the amounts of each product of oxidation formed over a period of time obeyed the same law as that which applied to the oxygen absorption indicating oxidation as a chain or step-by-step process.

Unfortunately a determination of the value of Q requires much time and is subject to considerable error. The values of k, from which those of Q are obtained, may vary in different samples as much as 10 per cent. Thus the final value of Q found in the present instance is 20,700 calories per mol, with a possible error of about 1,000 calories per mol. The value itself is apparently somewhat low, values as high as 45,000 for oils having been reported by other workers.

Using the value of Q as given above and its relation with k simple computation shows that at 45 degrees Centigrade, the value of k would be 0.0028 and that for saturation with oxygen this oil would require an induction period of 4 $^3/_4$ days. Thirty days after expiration of the induction period, the oil would have absorbed chemically 0.141 cubic centimeters of oxygen per gram of oil. This would cause a change in acid number of 0.0402 or a change in power factor of 0.00086. From these figures, it will be evident that for studies of this character an accelerated program at higher temperatures is imperative.

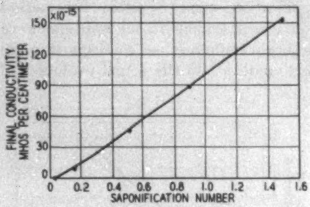


Fig. 19. Final conductivity versus saponification number at 40 degrees centigrade

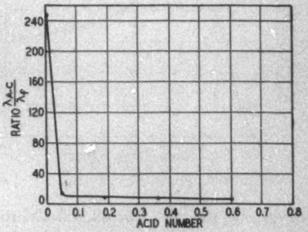
As regards the saponification number and the curve of figure 11 it is apparent that in the initial stages of oxidation there are proportionally more acids combined in the oil capable of forming metallic soaps than there are free acids. This curve as well as the quiescent period for carbon dioxide suggests that the initial oxidation of the oil up to acid number of about 0.2, while increasing acid content uniformly, also has a transient element serving to convert the oil from one oxidation state to another.

ELECTRICAL PROPERTIES

Of outstanding interest is the linear relation between acid number and power factor or dielectric loss. The initial or a-c conductivity of an oil is very much larger than the d-c conductivity measured after a long period of application of voltage. There is some evidence[21] that the ions involved in the 2 cases have different origins and perhaps different character. The difference between the 2 types is found only in purer and more highly refined liquids. With increasing impurities or deterioration such as oxidation in an oil, the difference between the 2 conductivities disappears and the ratio of initial to final conductivity approaches unity and the number of ions involved in the initial conductivity is submerged ultimately in those due to the oxidation or other cause. The transfer from the initial pure to a more deteriorated condition is clearly shown in figure 20. It is of interest to note, however, that the range of acid number for which the ions of the initial conductivity play an important part is relatively low. Their contribution to conductivity and power factor, is appreciable in the region of zero acid number, and causes the initial power factor of the oil. However they soon become relatively unimportant with increasing oxidation, nor do they at any point partake of an acid character. Various causes have been suggested for the origin of the ions causing the initial conductivity; as for example, ionic impurities of nonacid character, the liberation of electrons from the electrodes, internal liquid ionization by radio active or cosmic influence. The rate of generation of ions by the latter causes is quite low but over a period of time they accumulate in numbers up to an equilibrium condition, as related to the rates of recombination and diffusion to the walls of the container. They may be swept out temporarily by high continuous voltage, but on open circuit increase again slowly to their original number.[21] From the results of the present work, it is apparent that in the case of a highly refined oil, study of the correlation between the change in electrical properties and oxidation should take due account of the ions already present as shown in the short time conductivity, and of those due to oxidation, especially in the early stages. For later stages of oxidation, however, the initial conductivity plays no appreciable part.

The increase of dielectric constant with acid number as shown in figure 14 is apparently due to the presence of polar molecules, the polar property being well known for the oxidation products of hydrocarbons. The presence of polar aggregates much larger than molecules has been noted by Whitehead, but these larger aggregates are apparently absent in the present case for they are not evident in the short time d-c conductivity oscillograms, nor is there any measurable increase in the dielectric loss due to this cause. The variation in density over the most extended range of oxidation was less than 0.5 per cent indicating that the increase in dielectric constant is not due in any appreciable measure to increase of atomic polarization.

Fig. 20. Ratio (a-c conductivity/final conductivity) versus acid number at 40 degrees centigrade



In the matter of breakdown the transitory period in the oxidation process, involving as it does the molecular structure of the oil, seems to play a part. The breakdown strength increases, due perhaps to the oxidation or clean-up of residual impurities or the break-up of large unstable molecules with loosely connected valence bonds into smaller and more stable molecules. The subsequent decrease is apparently due to increased conductivity (Nikuradse[22]).

Considering then oxidation in its influence on the insulating properties of oils, we note 2 notoriously dangerous results, namely, increasing power factor and the evolution of gas. Increasing power factor means increasing dielectric loss and reduction of carrying capacity, and if the increase continues unabated, it leads definitely in the direction of failure. The evolution of gas means gaseous ionization with its well-known rapid destructive influence on fibrous impregnated insulation.

In the oil here studied we have shown a definite linear relation between the oxygen absorbed and the increase in power factor on the one hand, and the amount of gas evolved on the other. Consequently, for oil of this type it is clear that measurements of power factor and gas evolution, as related to oxygen absorbed, should constitute a reliable basis for the comparison of the oxidation stability of different oils. Moreover both measurements are important. At a recent meeting of the committee on electrical insulation, division of engineering and industrial research, National Research Council, R. W. Dornte divides oils into 3 classes as regards the rate with which they absorb oxygen in chemical combination. The oil studied in this paper falls in class (2), showing a rate of absorption directly proportional to the time. Several other papers presented at the same meeting indicated, however, that the oxidation products of various types of oil are proportional to the amount of oxygen and not to the reaction constant *k* which is a measure of the rate of oxygen absorption. Consequently it appears probable that the above correlations found in the single oil here studied will also be found in other oils.

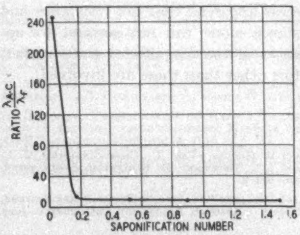


Fig. 21. Ratio (a-c conductivity/final conductivity) versus saponification number at 40 degrees centigrade

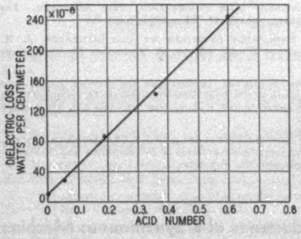


Fig. 22. Dielectric loss versus acid number at 40 degrees centigrade

E = 1,500 volts

VI. Conclusions

1. Accelerated oxidation studies have been made on a typical high-grade insulating oil. Linear relations are found over a wide range between the amount of oxygen chemically absorbed and time, acid number, saponification number, and carbon dioxide evolved.

2. Two periods of oxidation are indicated for the oil studied: (*a*) an initial transient period in which intermediate products are formed, (*b*) a subsequent period in which further oxidation does not materially add to the intermediate products, but increases the amount of the end products.

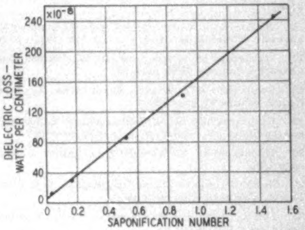


Fig. 23. Dielectric loss versus saponification number at 40 degrees centigrade

E = 1,500 volts

3. Similar linear relations have been found between the oxygen absorbed and power factor, dielectric loss, and long time d-c conductivities as measured at 40 degrees centigrade. The ratio of initial or a-c conductivity to final conductivity rapidly decreases with increasing oxidation in its early stages, thereafter much more slowly, indicating different natures for the a-c conductivities of refined and oxidized oils.

4. A relatively small, but apparently characteristic change in dielectric constant with increasing oxidation is due to the polar properties of the oxidation products.

5. With increasing oxidation the breakdown strength at first increases by about 5 per cent, passes through a maximum at about 0.2 acid number, and decreases again. These changes occur in the transient range of the oxidation processes.

6. The linear relation between oxygen absorbed and time leads to definite values of the reaction constant *k*, and to a constant value of the activation energy *Q*. Evidence is presented that the values of these quantities, obtained at higher temperatures, are reliable as good indices of the electrical behavior of the oil as related to oxygen absorption, at lower temperatures.

7. Evidence is presented indicating that the linear correlations found between oxygen absorption, gas evolved, and power factor increase in accelerated oxidation studies provide a reliable basis for estimating the relative oxidation stabilities of insulating oils.

VII. References

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Voltage Drop and Load Balance in Open-Y Circuit

(*Continued from page 437*)

feet will be about 1.2 volts and for the lagging phase about 3.2 volts. For a 500,000-circular-mil conductor, assuming the same conditions as for number 8, the voltage drop for the leading phase will be about 2 volts, and for the lagging phase about 1.25 volts.

As indicated by these curves the dashed lines are obtained by the difference in the voltage drop between the leading and lagging phases. At the point where each dashed line crosses the abscissa the difference in voltage drop between the leading and lagging phases is zero, hence the voltage drop is the same on both phases for the indicated amount of unbalancing and the indicated power factor. As shown by the curves for a number 8 conductor and a power factor of 0.9, the leading phase should carry about 60 per cent and the lagging phase about 40 per cent of the load. For a 500,000-circular-mil conductor and a power factor of 0.9, conditions are reversed and the dashed line crosses the abscissa at the point where the leading phase should carry about 40 per cent and the lagging phase about 60 per cent of the load.

Figure 4*A* condenses information about the proper load division between phases at various power factors in order to obtain balanced voltage conditions at the load.

These curves are very useful in determining the correct load balance between the leading and lagging phases in a building where the old d-c wiring is to be used. In such a case, the total load to be carried, the power factor, and the size of the conductors are fixed and the only variable will be the load balance between the 2 phases. The correct load balance can be determined specifically from the curves of figure 4*A*.

It will be noted that these curves have been derived for conditions where the power factors are the same on both phases. An infinite number of other conditions may arise in which the power factors will be different on the 2 phases. If a sufficiently large number of cases occur where certain definite power factors exist, curves of voltage drops for these conditions can, of course, be drawn.

Power System Faults to Ground

(*Continued from page 433*)

voltage per foot of arc length is practically independent of current magnitude and ranges between about 200 and 400 root-mean-square volts per foot of arc. The results offer a method of estimating, during the first few cycles of an arc, that portion of the fault resistance in the arc. For longer durations of fault, such estimates are likely to be inaccurate unless some idea of the length of extension of the arc can be secured.

(*d*) For steel tower lines carrying ground wires, tower footing resistance will have little effect on fault current magnitude if *l*, the length in miles of the section of line involved, is greater than

$$5\left(\frac{\sqrt{\text{average tower footing resistance}}}{\text{number of towers per mile}}\right)$$

In the case of steel tower lines with high-conductivity ground wires, it seems apparent that arc resistance and tower footing resistance alone will not account for apparent fault resistances of the magnitudes given earlier, indicating that factors other than these are involved.

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End-Winding Inductance of a Synchronous Machine

(*Continued from page 461*)

F = constant as defined by equations 16 and 17

h = radial dimension in centimeters of the conductors

K_p = reduction factor due to variable pitch

K_d = reduction factor due to distribution of conductors over a phase belt

K_c = reduction factor due to the peripheral distribution of the conductors

$k = \dfrac{bP}{dD}$

L = end-winding self-inductance in henries

L_{1d} = end-winding leakage inductance in henries with the field pole and phase axes coinciding

$l = \sqrt{b^2 + d^2}$

M_0 = maximum mutual inductance in henries between field and end winding

m = order of space harmonic

n = number of series connected conductors per pole per phase

n_f = number of turns of the field per pole

P = number of poles

K_h = reduction factor due to the radial distribution of the conductor

p = coil pitch

q = number of phases

ψ = linkage in abampere-henries per pole per phase due to the self-inductance of the end winding

Ψ = end-winding linkage in abampere-henries per pole per phase due to the mutual of the field

x, y, z = rectangular co-ordinates measured in centimeters as shown in figures 3 and 4

z_1, z_2, x_1, λ = field coil dimensions in centimeters as shown in figures 6 and 7

θ = slot pitch in electrical radians

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A New Magnetic Flux Meter

(*Continued from page 445*)

by means of calibration curves. Another slight disadvantage is that for all readings the current supplied to the bridge must be maintained constant.

The question naturally arises as to whether the bridge can be used for alternating or rapidly varying magnetic fields. Tests made during this research prove that readings are obtained as readily in alternating fields as in stationary fields, but no calibrations have been attempted as yet because of lack of apparatus and time. The reports of previous research [10,11,12] appear to indicate a lag in the change of resistance of the bismuth, though it may not be serious enough appreciably to effect the accuracy of the bridge at low frequencies, perhaps even up to 60 cycles. Further research in the use of the bridge for the alternating flux field appears to be highly desirable.

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Voltage Regulator Utilizing Nonlinear Circuit

(*Continued from page 464*)

tively. Inspection indicates that operation is completed in 15 to 20 cycles after the disturbance, and that this delay is largely due to the time constants of the machines used rather than the control circuit, which effects the maximum possible change in the rectifier plate current in less than 5 cycles after the disturbance. By its nature, the arrangement is well damped, and no auxiliary circuit was necessary to prevent or reduce hunting.

The regulator arrangement just described would be quite flexible in application since the counter-electromotive-force machine could be designed to control a generator of any size without increasing the tube rating required. In some cases, however, the complication of an extra machine might be undesirable, and therefore the modification shown in figure 6 was developed. The excitation of the alternator is supplied by a standard shunt machine. The shunt field is also connected in the plate circuit of the rectifiers so that the rectifier plate current opposes the exciter field current produced by the exciter terminal voltage. Hence an increase in alternator terminal voltage will produce an increase in rectifier plate current just as before, and this will decrease the total field excitation of the exciter with a corresponding decrease in the exciter terminal voltage thus bringing the alternator voltage back to normal. There will also be the second order effect of the decreased exciter terminal voltage on the exciter field excitation produced by the ordinary action of a shunt machine, and this will be in the proper direction for assisting regulator action. The circuit of figure 6 was even more effective than that of figure 4 utilizing the same machines as before. When properly adjusted, there was no readable change in voltage from full load to no load. The oscillograms shown in figures 7*a* and 7*b* illustrate the speed of operation of the regulator which is again largely a function of the machine time constants.

This method could be applied to large machines by increasing the rating of the tubes used, or by providing an exciter with 2 field windings. One of these windings would be used as the regular shunt field, and the other would be separately excited by the rectifier tubes. By properly proportioning the separately excited winding, small tubes could be used to control the larger machines. The addition of a low-rating single-phase voltage-adjusting transformer between the source and the nonlinear control circuit would permit operation at any desired voltage above or below nominal rating.

Conclusion

Because of the wide variation possible in machine constants no definite comparisons between this and other types of regulators can be made. Even under the conditions which this circuit was tested, however, it produced sensitivity and operating speed comparable with any of the existing electronic types with the decided advantage of simplicity of design. It has no moving parts, and the only attendance required would be the periodic inspection and testing of the rectifier tubes. Even if both tubes should fail simultaneously in service, a very unusual occurrence, the worst possible result would be the operation of the alternator at light load with a field excitation corresponding to normal voltage at full load. In case of short circuits on the system, the field excitation can only exceed that required to maintain normal voltage at full load by a predetermined amount, and hence the severity of short circuits will be lessened. If the frequency drops, the regulator will still exercise considerable regulatory action at subnormal voltage. If the frequency rises the control circuit will be sensitive at a higher value of voltage, and would regulate for this voltage if the field excitation for maintaining this voltage were available. Usually, however, the field excitation would be only slightly greater than normal full-load value, and the regulator would be inoperative except at light loads.

Thus we see that the regulator herein described has a number of advantages over other types without any apparent disadvantages.

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Special Uses for the Automatic Oscillograph

(*Continued from page 440*)

110-kv system. Applying the 6 volts direct current to this element gives an offset to the a-c wave during the interval that the tripping circuit is open. This is shown in figure 4. A similar arrangement of connections is made to the carrier receiver relay on the second 132-kv circuit and the d-c offset is obtained on another a-c voltage element of the oscillograph. The oscillograph battery is used for the offset on one circuit, and in order to eliminate the possibility of short-circuiting the secondaries of 2 potential transformers, a separate battery is used for the offset on the other circuit.

With this arrangement it is possible to check the over-all time required for the relays on each circuit to operate and open the trip circuit, and also the time required for them to reset and stop carrier after the fault is cleared. Comparing the times required by the relays on each circuit with the times obtained on the previous calibration and test, will indicate any change in total time which has taken place. A change in the total time may be due to any one of a number of relays, but by checking this total time it is possible to determine when a special calibration and test should be made on the individual relays.

Conclusions

The operating records shown indicate that the use of the automatic oscillograph in locating faults, affords a means of reducing the cost of patrolling circuits after trip-outs. The annual saving, especially on systems composed of long circuits and whose terrain is subjected to a large number of electrical storms, makes the installation of several automatic oscillographs a profitable investment.

Temporarily connecting the automatic oscillograph to obtain a complete over-all check of the carrier-current-controlled relays is a new aid in insuring the correct operation of the relay protection for all types of trouble.

By using the oscillograph to indicate the performance of the carrier-current-controlled relays for faults both inside and beyond the protected section, complete over-all checks can be made less frequently with a subsequent saving in maintenance costs.

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Discussions

Of AIEE Papers—as Recommended for Publication by Technical Committees

On this and the following 4 pages appears a part of the discussion presented at the electrophysics session of the AIEE winter, convention, New York, N. Y., January 28, 1937. Other discussion of winter convention papers will be published in later issues. Authors' closures, where they have been submitted, will be found at the end of their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in Electrical Engineering, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions of papers presented at an AIEE meeting or convention are closed 2 weeks after presentation. Discussions should be double-space typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, AIEE headquarters, 33 West 39th Street, New York, N. Y.

A-C Characteristics of Dielectrics—II

Discussion and author's closure of a paper by Alfredo Banos, Jr., published in the December 1936 issue, pages 1329–37, and presented for oral discussion at the electrophysics session of the winter convention, New York, N. Y., January 28, 1937.

J. B. Whitehead (The Johns Hopkins University, Baltimore, Md.): Only a few years ago our knowledge of the nature of dielectric loss was extremely vague. With increasing importance of dielectric loss and phase difference in high-voltage insulation, however, it was soon realized that the d-c phenomenon of residual charge or dielectric absorption must be related to dielectric loss. Theories as to the cause of dielectric absorption were not then, nor are they now, in quantitative accord with experiment. Consequently Von Schweidler, leaving aside the question of theory, substituted the relaxation function $\varphi(t)$, expressed as current in the normal a-c power expressions, and derived the values of both in-phase or power, and quadrature or capacitance components of the periodic current of a capacitor. These values both involve $\varphi(t)$ which consequently had to be determined for their evaluation. Now $\varphi(t)$ can be determined from d-c experiments. It so happens, however, that $\varphi(t)$ so determined, is rarely such a form that it can be expressed in a single term. All such decaying functions, however, can be expressed as a sum of negative exponential terms, and these are readily handled in the Von Schweidler formulas. If, however, the number of such terms necessary to represent $\varphi(t)$ is large, the computation becomes rather burdensome.

The method of 3 exponentials has been developed because it has been found that in the range of power frequencies, 3 terms are amply sufficient: first, for accurate computation of the a-c loss from the d-c characteristics of the material, second, the division of that loss into its 2 components due to dielectric absorption and anomalous conduction, respectively, and, third, because this analysis provides information upon which studies looking to the improvement of any particular insulation may be based.

The present paper shows that for agreement between computed and measured values of the capacitance component of current, the curve of $\alpha(t)$ must be extended further in the direction of $t = 0$, than is the case for the power component. Baños has given a very clear analytical explanation of why this is so.

M. G. Malti (Cornell University, Ithaca, N. Y.): I have been interested in theories of dielectrics for some time. To me a physical theory consists of linking physical facts with mathematical relations in a one-to-one correspondence so that every mathematical relation corresponds to a certain physical fact and vice versa.

The "method of 3 exponentials" described in this and the previous paper does not state explicitly what the 3 exponentials represent physically. Unless there is a physical basis for the 3 exponentials, I feel inclined to state that the method is purely a curve-fitting process and has nothing to do with the "A-C Characteristics of Dielectrics." Indeed while these exponentials were used by the authors to "fit" the relaxation curve, I see no reason why that same curve could not be just as well (perhaps much better) "fitted" by a polynominal or any other of the myriads of mathematical functions known to mathematicians and engineers.

The point I should like to make is this: Many of the so-called theories of dielectrics have been nothing but curve fitting processes. Unfortunately physicists are too busy splitting atoms and otherwise probing into the constitution of matter to help us with our immediate practical problems of dielectrics and magnetics. Those of us who are concentrating our efforts on such studies would do well to emulate the physicists and devote more attention to the fundamental *physical* phenomena underlying observed facts.

W. A. Del Mar (Habirshaw Cable and Wire Corporation, Yonkers, N. Y.): It may seem like quibbling to take exception to the use, by Baños, of the expression "predetermination of a-c characteristics" but I think that a very incorrect impression of the paper is given thereby. The author's accomplishment is not one of prediction but of correlation between the residual relaxation curve obtained by d-c measurements and the power factor obtained by tests at 60 cycles. This is done by the resolution of the residual relaxation curve into the sum of a series of exponential curves. The same thing would be done by using some other empirical formula for this curve. When one writes a theoretical paper on the predetermination of performance of a dynamo, one implies the ability to predict the performance of the dynamo from the design, before the dynamo is built. In the Baños paper the dielectric must be in existence and can be tested with alternating current as easily as with direct current.

A means of really predicting power factor of impregnated paper from d-c measurements of oil and paper before impregnation was given by Del Mar and Hanson in June 1922 and the curve given by Hanson for petrolatum impregnated cables (AIEE TRANSACTIONS, volume 41, 1922, page 624) is very striking in its close co-ordination between the prediction and the measured value. This method of predicting power factor is based on the conventional one-minute resistivity of the cable oil. If the residual relaxation function were always the same, a single point, such as corresponding to one minute, would suffice to establish a connection between the one-minute $\frac{dE}{dI}$ or conventional resistivity, such as shown by Hanson's curve. If, however, the residual relaxation function is variable and must be represented by the sum of, say, 3 exponential fuctions, the factors representing the magnitude of these components are likely to vary with different oils and papers and true prediction of power factor (that is, prediction from the properties of the oil and paper, before they are united), will be impossible unless these factors are known for the oils and papers concerned. It would be a worth-while research to develop a simple means of predetermining these factors.

I have a classification for researches which is as follows:

1. Those which are headed somewhere and get there.
2. Those which are headed somewhere and get somewhere else.
3. Those which are headed somewhere and get nowhere.
4. Those which are headed nowhere and get somewhere.
5. Those which are headed nowhere and get nowhere.

When I first read Baños' paper and my eye was caught by the word "predetermination," I thought that his research belonged in class 2, but I now see that it really belongs in class 1.

E. W. Greenfield (Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.): As Baños has pointed out, the frequency function of the quadrature component of absorption permits contributions from the unobserved so called residual relaxation function which must be taken into account in order to accurately predict the a-c dielectric constant from the d-c absorption curves. The initial residual relaxation function is the difference between the relaxation function of the exponential of shortest time constant, and the relaxation function of that part of the initial curve not recorded by the oscillograph and expressed also in exponential series. When this residual relaxation function is large, its contribution is large and the "3 exponential" computed absorption component of capacity will be appreciably smaller than observed by frequency measurements. Another way of expressing the above is to say that the effective time constant of the d-c characteristic as computed from the experimentally taken oscillograms is too large when no account is taken of the initial unrecorded characteristic which has generally smaller time constants. The smaller the time constants, or the steeper the slope, of this unrecorded portion, the greater the deviation between computed and observed values.

If the frequency-capacity variation for the dielectric be available, a check of the range of frequency over which the absorption component of dielectric constant falls before reaching constant value will immediately indicate the range of time necessary for the oscillograph to accurately record the d-c characteristic. Where the dielectric has an extended frequency range of capacity decrease, the time constants or, for simplification, the effective time constant of the exponential function series representing the whole initial d-c characteristic, will be small and considerable contribution can be expected from the higher frequency terms. Where the frequency range of capacity is small, not over 500 cycles per second, oscillograph records starting at one millisecond may yield quite accurate prediction of the absorption component of capacity at 60 cycles.

In the experimental work on dry paper referred to by Baños, AIEE TRANSACTIONS, volume 53, 1934, page 1389, Whitehead and I have shown in figure 4, curves of capacity plotted against frequency for a cable paper specimen of varying degrees of dryness. Inspection of these curves indicates that the range of frequency over which the capacity is seen to decrease is different for each moisture condition, being smaller in the drier state. For example, when dried at 765 millimeters of mercury, the capacity decreased continuously from its 60-cycle value to become constant at 3,000 cycles per second. On the other hand, for the paper in its driest state, the range of capacity decrease was only over 500 cycles. From this it is evident that the form of the relaxation function of the dielectric has been altered by its change in residual moisture content. This is also evident on figure 5, where the short-time d-c discharge curves of the dielectric are shown. Increase of moisture content is apparently responsible for addition to the relaxation function of components of small time constant, and thus causes an increase of the so-called residual relaxation function. Based on the frequency-capacity curves of figure 4, it may then be predicted that the correlation of absorption component of capacitance between a-c and d-c measurements should be better for the driest condition and poorest for the most moist condition. That this is so is evident from table I, which gives the power factor and capacity analysis of the d-c oscillograph curves. In columns 8 and 9 the agreement between observed and computed values of absorption capacity is generally better as we proceed from moist conditions to dry conditions of the dielectric.

Alfredo Baños, Jr.: I feel grateful to Whitehead for his pertinent remarks which ably summarize both the purpose of our earlier researches and the goal actually attained in these studies. It is clear from our publications that, in this aspect of the work, we have at no time professed to give a theory of dielectrics, but that we have simply brought Von Schweidler's method of a-c computation to the domain of experimental quantitative verification and that, in so doing, we have developed a method of separating dielectric loss into its 2 fundamental components: reversible absorption and anomalous conduction. The importance of this achievement, not only from the theoretical point of view, but also from the standpoint of high voltage insulation design, is now generally well recognized and need not be further stressed.

In connection with Malti's discussion I must again reiterate that we offer no theory of dielectrics; hence our "3 exponentials," which are only a means to an end, have no physical significance. In fact, casual study of our method of "curve fitting," as explained in our first publication, should leave no doubt that, on account of its inherent indeterminateness, the 3 exponentials lose all hope of ever attaining a definite physical meaning. I do insist, however, that from among the myriads of junctions known to mathematicians and engineers, the exponential function is the best suited for our purpose. Indeed, a clear understanding of Von Schweidler's method of a-c computation depending, as it does, on the determination of 2 infinite definite integrals whose convergence requirements must be carefully inspected, should make it plain why the exponential function is admirably suited for the purpose at hand and why any other function, a polynomial, for example, while fitting the relaxation function accurately for a limited range of time, could not yield at all reasonable values for the *A* and *B* integrals in Von Schweidler's method.

Referring to Del Mar's discussion I agree that the title "correlation of a-c and d-c characteristics of dielectrics" would undoubtedly give a better idea of the subject matter treated. I do take exception, however, to the statement that correlation between the d-c characteristics and the a-c power factor could be attained by the use of any empirical equation representing the relaxation function, for, as explained in the preceding paragraph, the exponential is the simplest function which complies with the convergence requirements of the method.

To E. W. Greenfield I wish to express my appreciation for his excellent and thorough discussion of my paper, bringing out clearly the correct interpretation of our results together with an enlightening set of remarks based on his own experimental results which, in themselves, constitute a valuable supplement to our conclusions.

Dielectric Strength of Transformer Insulation

Discussion and authors' closure of a paper by P. L. Bellaschi and W. L. Teague published in the January 1937 issue, pages 164–71 and 137, and presented for oral discussion at the electrophysics session of the winter convention, New York, N. Y., January 28, 1937.

J. B. Whitehead (The Johns Hopkins University, Baltimore, Md.): The fundamental dielectric properties of an insulating material can rarely be conserved and maintained through the processes of manufacture, transportation, installation, and operation of assembled equipment. It is for this reason that the results and values obtained in laboratory research may not be immediately applied in manufacture. The paper of the present authors and that of Montsinger, a few months ago, describe results of breakdown tests on oil and laminated materials with almost identical types of test sample. These test samples, however, in all cases employ an electrode with square edges and without guards which is recognized by long experience as being a very unsuitable set-up for a study of the inherent characteristics either of a liquid or a solid. Obviously, therefore, these and similar tests cannot be considered as tests of the properties of the insulating materials, but are tests of these materials in relation to special types of electrodes. Moreover, these electrodes are known to give highly irregular fields, brush discharge, corona, etc., long recognized as disturbing influences in breakdown tests.

These things may be said without in any way questioning the practical importance of such tests. They are evidently designed to cover the actual conditions under which the insulation must be assembled in manufacture. This is obviously a sufficient justification for any design of test sample. I judge that the use of a sharp edge is intentional so as to produce the worst conditions, but if the tests are in accord with measurements on assembled power transformers, as is indicated, the question arises as to whether the breakdown strength of these might not be improved by looking for all sharp edges and rounding them off.

It seems to me idle in view of the conditions of the tests, involving as they do the continued presence of brush discharge and corona, to write formulae for the voltage-time curves, or to speculate as to an explanation of their unusual shape. In view of the results of many careful experiments on the inherent properties of the materials themselves, I strongly suspect that the sharp rise of the curve of measured breakdown voltages for short impulses does not give the actual voltage on the sample, but that within this region the rise of voltage above the horizontal portion of the curve is due to a loss in voltage within the brush discharges, corona, and local capacitances within the sample itself. Support of this view is found in a number of cases in which the solid insulation broke down at points outside the electrode.

J. R. Meador (General Electric Company, Pittsfield, Mass.): The authors, under the heading of "Combined Solid and Liquid Insulation," give impulse and 60-cycle breakdown voltages for an insulation barrier consisting of 2 0.056-inch thick fullerboard sheets and 3 $^1/_8$-inch oil ducts arranged alternately. The impulse tests were made with waves having durations of from 0.35 microsecond to a full 40 microseconds. Over this range the impulse ratio on repeated applications of voltage is shown to be practically constant at 2.2. In a previous paper ("Insulation Coördination of Transformers—II," by Bellaschi and Vogel, June 1934 issue of ELECTRICAL ENGINEERING) similar tests are made on 2 larger barriers. These tests showed an impulse ratio on repeated applications of voltage of 1.79 and 1.78. Three possible explanations for this difference of impulse ratio are as follows:

1. A change of technique giving different results.
2. A change in the shape or size of the electrodes.
3. A change in the insulation arrangement.

Assuming that the difference is not due to cause 1, it appears that different insulation arrangements and electrode sizes and shapes have an effect on the repeated shot impulse ratio. Consequently, it does not appear logical to use the maximum impulse ratio of 2.2 for determining the impulse test for transformers of all voltage classes.

The tests on the assembled transformers presumably were made without damage to the transformers. If no damage occurred, then the "turn up" of the voltage at short "times" on figure 10 has significance only if the relation between the applied voltage and the breakdown voltage is constant in each region.

With regard to the switching surge tests shown on figure 10, what was the frequency of the switching surges as compared with the lowest natural frequency of the transformer winding?

It has been shown ("Effect of Transient Voltages on Power Transformer Design," K. K. Paluev, AIEE TRANSACTIONS, volume 48, July 1929, page 681) that oscillatory waves caused by switching or arcing grounds may have frequencies comparable with the natural frequencies of transformer windings. This is of importance since an oscillatory wave applied to an unshielded transformer will cause high concentrations of voltage in the winding if the frequency of the wave is within plus or minus 40 per cent of one of the natural frequencies of the winding. If the frequencies of the switching surges represented by the points on figure 10 were considerably less than the lowest natural frequency of the transformer winding, the effect of these tests on the winding was not comparable with the stresses that may occur in service.

V. M. Montsinger (General Electric Company, Pittsfield, Mass.): This paper gives very complete data on the volt-time curves on various oil gaps and on single sheets of pressboard. The statement made by the authors that more data were required to establish adequately the volt-time characteristics of insulation needs to be qualified. If they are referring only to the characteristics of oil alone and to solid insulation alone, I more or less agree with them, but if they refer to insulation as used in transformers, particularly major insulation, I must take exception to the statement in so far as it relates to the increase in the breakdown strength for short waves of the order of approximately one microsecond and less.

My experience shows that the volt-time curve of solid insulation and oil in series starts bending up in the neighborhood of 2 to 3 microseconds and bends up considerably more than shown in either figure 6 or figure 7 of the paper. In fact, considering that the volt-time curve of oil alone as shown in figures 3, 4, and 5 starts bending up around 10 microsecond—and the breakdown strength increases in the order of 100 per cent for $^1/_2$ microsecond time—it is to be expected that the volt-time curve of transformer major insulation, where oil is used in series with solid, should not only start bending up earlier but also should bend up more than shown by the authors' curves for pressboard alone. Figure 4 shown in the closure of my paper "Breakdown Curve for Insulation," given (in the April issue of ELECTRICAL ENGINEERING) at last winter's convention, shows the bend-up in the curve as indicated by tests made by both Vogel and myself on various thicknesses of barriers. This curve shows that the breakdown strength at one microsecond is 25 per cent greater than the full wave breakdown strength and at $^1/_2$ microsecond is approximately 50 per cent greater than the full wave strength.

Since the presentation of my paper last winter, our Laboratory has made many hundreds of tests to determine the shape of the volt-time curve from approximately 3 microseconds back to $^1/_2$ to $^1/_4$ microsecond on barriers of different thicknesses and based not only on single shot breakdown, but on repeated applications of voltage. A still better gauge than repeated voltage breakdown is the point at which corona starts to damage the insulation. This also has been investigated. While the tests are not yet completed, results up to the present time indicate that for full waves the injurious corona point will range anywhere from approximately 70 to 90 per cent of the single shot breakdown depending on the kinds of electrodes used. For bare electrodes with sharp edges injurious corona may start around 65 to 70 per cent while for well insulated electrodes injurious corona may not start until about 90 per cent of the breakdown strength is reached. For average conditions I think we can assume that injurious corona (or breakdown if subjected to sufficient number of shots) occurs at 80 per cent of the single shot breakdown value. This applies to either solid or solid and oil in series.

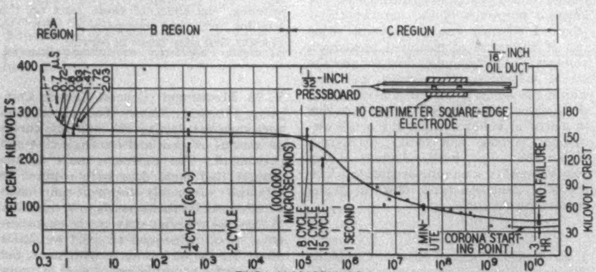


Fig. 2. Volt-time curve of single shot breakdown of 2 $^1/_{32}$-inch pressboard and $^1/_{16}$-inch oil duct in series in oil at 25 degrees centigrade

The shape of the curve is somewhat similar to but does not bend up quite as much as the single shot breakdown curve as shown in figure 1. The purpose of these tests is, of course, to obtain basic data for protecting transformers in service against both long waves and short waves. As it is planned to give the results of these tests in a paper for a later convention, no attempt will be made to present the data in this discussion. It can be seen therefore, that before rules can be drawn up for testing transformers on the front of waves, we must have considerably more data than has been published up to the present.

Last winter when my paper on "Breakdown Curve for Insulation" was presented, the question was raised as to whether major insulation of transformers, consisting of solid insulation and oil in series, had the flat characteristics; that is, the constant breakdown strength over the region in time from approximately 3 microseconds to 1, 2, or 3 cycles of 60-cycle voltage. Since that time tests have been made on a barrier consisting of 2 $^1/_{32}$-inch pressboard sheets separated by $^1/_{16}$-inch oil duct. The results of these tests are shown in figure 2. It will be noted that where 50 per cent of the space is occupied by oil, the other 50 per cent by solid, the shape of the curve is essentially the same as the curve for a single sheet of pressboard.

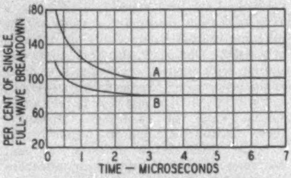


Fig. 1. Volt-time curves of insulation consisting of solid and oil in series, simulating major insulation in a transformer

A—Breakdown by single application of voltage
B—Breakdown by repeated application of voltage (approximate) 1.5 × 40 impulse wave (positive or negative)

As the primary purpose in making these tests was to determine the characteristics within the flat region, no breakdown tests were made with extremely short waves to determine the bend-up in the curve from approximately one microsecond and less. A considerable amount of data has already been obtained on this point.

In view of the results which our laboratory has obtained on the breakdown strength of many barriers on front of wave tests, as compared with breakdown for full waves, I am at a loss to understand why the authors' tests show the same breakdown strength of 300 kv for 0.35 microsecond as for $2^1/_2$ microseconds on the insulation barrier consisting of 2 0.056-inch thick pressboard sheets and 3 $^1/_8$-inch oil ducts arranged alternately, as given on page 170.

I believe it can readily be appreciated that the main difference between my views and the authors' views is that the authors feel that when short or front of wave tests are made on transformers, the kilovolt values should not be allowed to exceed the kilovolt values used for the full wave tests, whereas my views, as based on laboratory tests, indicate that a somewhat greater increase in kilovolt values can be used when testing transformers on the front of the wave.

As to the claim that the impulse test kilovolt should be 2.2 times the 60-cycle crest test, many tests made on actual transformer windings have shown impulse ratios varying from about 2.2 to 3, the general average being approximately 2.6. This applies only to single wave impulse strengths of major insulation.

Under repeated voltage conditions the impulse strength of the major insulation is obviously lower than 2.2 to 3 times the 60-cycle one-minute strength, the reduction depending upon the difference between the impulse single voltage application and impulse repeated voltage application strengths of the insulations involved. The repeated impulse strength of transformer windings is in the order of 80 per cent of the single shot strength. That is, it will range from about 1.75 to 2.4 with a general safe average value of approximately 2.0 times the 60-cycle one-minute strength. Therefore for a 138-kv transformer the impulse kilovolt should not exceed $2\sqrt{2} \times 277 =$ 782 kv which is quite close to the present AIEE recommended value of 745 kv which is 105 per cent of the bushing flashover.

I. W. Gross (American Gas and Electric Company, New York, N. Y.): This paper is a worthy contribution to the rather meager published data on the electrical strength of insulation typical of that used in transformers. I particularly wish to compliment the authors on the completeness with which they have substantiated their test curves by showing test points in all of their curve data.

In regard to the switching surge tests, it is not clear from the paper if one impulse only was applied or whether the surge consisted of several high frequency cycles similar to actual switching surges recorded in the field by the cathode ray oscillograph. If only one impulse was used it seems possible that the values of insulation breakdown might be somewhat lower than given by the authors.

The tests shown graphically in figure 10 throughout a wide range of voltage conditions on full size commercial transformers are particularly interesting, but the logic behind some of the conclusions drawn from that data is difficult to follow.

First, it is stated the test in region *E* (these being front of wave tests where the wave rose to crest in from $^1/_2$ to 1 microsecond) encroach on the margin of the insulation impulse strength. Yet it will be noted one transformer withstood 15 tests in this region, and the other 4 tests. It is hard to understand why they believe the test in this case was excessive, and there appears to be nothing in the paper to bear out this statement.

They further state that "these tests on the transformer are amply indicative that the voltage time characteristics of this and other apparatus of the kind is similar in shape to that for oil and fullerboard." While I do not question the latter part of this conclusion, the fact must not be lost sight of that the transformers *withstood* the tests, but the samples of oil and fullerboard *failed* all under similar voltage test conditions. It seems quite possible, therefore, that the transformers may have a safe impulse strength, at some points on the volt-time curve given considerably greater than the values at which they were tested.

The authors further state that the large number of tests made on the 2 transformers with impulse and 60-cycle voltages "are sufficient to establish the adequacy of a transformer design for practically all conditions of service." This statement assumes a great deal as to service which often may not be reasonably attainable in practice.

I certainly hope their statement is correct; for if so, most of us would cease to worry about many of the refinements in supplying transformers with protection which have recently been advocated.

It is true the large number of tests on these 2 transformers do tend to give us some assurance that transformers can be built to adequately meet a given set of insulation specifications; but I believe we still have with us the practical problem of protecting these transformers under the varying conditions of service encountered in the field.

P. L. Bellaschi and W. L. Teague: In his discussion, V. M. Montsinger calls attention to the relation between the impulse strength of insulation for a single voltage application and for repeated applications. His conclusion is that the impulse voltage on transformers should not be more than 2.0 times the 60-cycle one-minute strength, thus for a 138-kv transformer the impulse kilovolts should not exceed $2.0\sqrt{2} \times 277 = 782$ kv. This is an important conclusion to consider as it essentially comprehends the various points considered throughout the discussion. In this connection reference to figure 10 of the author's paper clearly shows that impulse tests up to $2.2\sqrt{2} \times 277 = 860$ kv could be applied repeatedly on the 132-kv transformers, both shell and core types. Similarly, in a previous paper where the fundamental relations on possible insulation deterioration on repeated impulses of long, medium, and very short duration were first set forth ("Factors Influencing the Insulation Coördination of Transformers—II," P. L. Bellaschi and F. J. Vogel, ELECTRICAL ENGINEERING, June 1934), attention was called to repeated tests on 230-kv transformer design at $461\sqrt{2} \times 2.2 = 1430$ kv.

In Montsinger's discussion, he refers to tests made by both Vogel and himself on various thicknesses of barriers, and that they showed an increase in breakdown strength at very short times. I would like to call attention to the fact that Vogel has not published data showing this to be the case for repeated tests, as his data are shown in the paper just referred to. It should also be noted that the data previously reported referred to a particular type of barrier and electrode arrangement, representative of the higher voltage transformers, and not including other arrangements used on lower voltage transformers.

Curve *A* of figure 1 for the breakdown of insulation by single application of voltage is well known. It appears, for example, in figure 1 of the paper cited in a previous paragraph. The curve *B* of figure 1 for repeated applications is interesting, but it is not clear from the discussion whether the author considers this as a specific or a general curve. For example, tests have been made where the corresponding curve *B* rises much higher on very short impulses than indicated in figure 1 ("Direct-Stroke Protection of Distribution Transformers," H. V. Putman, *Electric Journal*, February 1937, page 60). The converse is possible for other apparatus. Curves such as *B* of figure 1 need be clearly specified with reference to the apparatus or test specimen, number of voltage applications, and similar essential information.

Montsinger has presented additional data of interest on the characteristic of insulation over the "region *B*," that is, from some 2 to approximately 100,000 microseconds. His figure 2 further confirms that the voltage characteristic of transformer insulation is practically flat over the entire range of medium and long impulses and switching surges.

The point raised by Meador that change in shape or size of electrodes or in the insulation arrangement may result in different levels of possible damage is quite true as has been discussed in the previous paragraphs. Thus distribution apparatus has a relatively higher strength and endurance to repeated impulses than the higher-voltage class insulation. Again, the ratio of 2.2 indicated in figure 10 has been established by repeated tests.

The question of switching surges in relation to so-called possible resonance effects has always been intriguing. Available data (see, for example, *C.I.G.R.E.*, 1935, paper 353, and similar data published here) indicate that true oscillatory voltages superimposed on the 60-cycle wave are relatively of low value. The higher values that may be encountered are impulsive in character. For these reasons the tests applied to one of the transformers are amply severe both from the standpoint of oscillations and amplitude. Repeated tests running into the hundreds were applied at values $3^1/_2$ the operating voltage and in addition, as indicated in figure 10 the voltage was raised to 5 times and more the operating voltage. The character of these switching voltages is abruptly steep and enduring for hundreds of microseconds, fully developing all internal oscillations. These would produce stresses more severe than could be accounted for even had the wave been in resonance and of such amplitude as has been encountered in practice. Our own experience has not yet shown failure due to switching causes even on under-insulated transformers.

We well agree with Whitehead that the tests and data in the paper are primarily of an engineering character and are directed chiefly toward engineering progress in insulation co-ordination. Though the results also bear out interesting findings of a theoretical nature. It is amply apparent from this discussion that in the design of apparatus all possible causes of corona should be completely or practically suppressed. The rise in the voltage time-lag characteristics, to which Whitehead refers, has also been found by other investigators both in this country and abroad (on oil, for example, see *C.I.G.R.E.*, 1935).

I. W. Gross rightly raises the point whether the limited tests applied to the 2 transformers in the region *E* (figure 10) do encroach on the insulation, since they withstood the tests. A considerably greater number of repeated tests indicate that damage would result. It is apparent from this cumulative effect that a smaller number of tests would also encroach, in a certain measure on the margin factor of the insulation.

The voltage values in region *D*, *C*, and *B* were limited by the rod gap. Were no gap employed the bushing would naturally set a limit of the same relative order. These hold values should be considered in relation to the major insulation strength and the strength throughout the entire winding for the corresponding stresses set up. To continue these tests to breakdown would require an increase in rod gap spacing or what amounts to the same thing, a higher voltage bushing. Between the ultimate strength and the hold strength naturally a margin exists.

Even after fulfilling by proper design and adequate test the requirements in a transformer, the problem of protection remains. It was not the intention a all to convey such idea that this problem would be dispensed with. One purpose of this paper, supported by the tests, is to call attention to the full significance of the 60-cycle and impulse tests as an index to an expectancy of good service in the transformer. The preceding paper to this one ("Factors Influencing the Insulation Coördination of Transformers—II," P. L. Bellaschi and F. J. Vogel, ELECTRICAL ENGINEERING, June 1934) presents fundamental considerations underlying the problem of protection in relation to the characteristics of substation apparatus. We wish to recall the attention to these principles, even though each case of application may in addition present problems inherent in the particular service conditions.

The switching surge applied in the insulation tests appears in oscillogram *D* (figure 8). The surge is oscillatory; besides 60-cycle voltages of equally great amplitude were applied the insulation for several oscillations, indicating with adequate assurance that the voltage-time characteristic for the various possible conditions of switching can hardly be other than a flat curve. The transformer was subjected (figure 1) to a large number of repeated surges at $3^1/_2$ times the operating voltage, then in addition at 5 times and more as indicated on figure 10. These switching voltages are abruptly steep and enduring for hundreds of microseconds, comprising a severe test.

News

Of Institute and Related Activities

Elihu Thomson—

March 29, 1853—March 13, 1937

CONCLUDING one of the longest, most varied, and most fruitful careers in electrical engineering, Elihu Thomson died at his home in Swampscott, Mass., on March 13, 1937, just a few days before his eighty-fourth birthday. Indisputably the dean of American electrical engineers, he was regarded as being second to none among the small group of his contemporaries upon whose inventive genius the electrical industry of the world was founded and through whose perseverance and keen foresight it grew.

Recognized for his character and ability, and honored by his contemporaries throughout his lifetime, few men, if any, have contributed more to the progress of the world than did Elihu Thomson, and fewer still have lived to see such full fruition of their ideas. He was one of the last of the original group of great electrical pioneers.

His signature was on the "call" for the May 1884 organization meeting of the AIEE, and Doctor Thomson became a charter member of the Institute. He maintained an active affiliation for the remainder of his life. He is survived by only 3 other charter members whose names still appear on the active list. Although not caring for administrative work, preferring to remain "in the ranks" and closer to his work, Elihu Thomson was elected a vice-president of the Institute in 1887 and immediately upon completion of his term in that office became in 1889 the fifth in the line of great leaders who have guided the Institute's destiny.

Doctor Thomson was particularly active in local Institute affairs, and a perusal of the AIEE PROCEEDINGS prior to 1910 will show that he presented papers and discussions at many Section meetings. He served as a member of the Institute's committees on co-operative research and standardization from 1898 to 1900, and as chairman of the Edison Medal committee from 1911 to 1915. Thomson was not a prolific scientific writer, but the character of his writings is attested by the following papers published in the AIEE TRANSACTIONS:

1. NOVEL PHENOMENA OF ALTERNATING CURRENTS, volume 4, May 1887, page 160.

2. MAGNETISM IN ITS RELATION TO INDUCED ELECTROMOTIVE FORCE AND CURRENT, volume 6, May 1889, page 269.

3. PHENOMENA OF ALTERNATING-CURRENT INDUCTION, volume 7, April 1890, page 132.

4. COMPOUNDING DYNAMOS FOR ARMATURE REACTION, volume 12, June 1896, page 288.

5. A NEW FORM OF INDUCTION COIL, volume 14, July 1897, page 225.

6. CONDITIONS AFFECTING STABILITY IN ELECTRIC LIGHTING CIRCUITS, volume 28, January 1909, page 1.

In 1904 the Institute, in response to an invitation by an organization of associates and friends of Charter Member Thomas A. Edison, undertook the responsibility of making the awards of a gold medal now known as the Edison Medal. Elihu Thomson, in 1909, was the first to receive the award "for meritorious achievement in electrical science engineering, and arts, as exemplified in his contributions thereto. . . ."

In June 1928 the Institute was priviliged to give further recognition to Thomson's services and achievements. The constitution provides that Honorary Members may be chosen, upon the *unanimous* vote of the board of directors, "from among those who have rendered acknowledged eminent service to electrical engineering or its allied sciences." Prior to June 1928 the few distinguished persons thus elected all were from foreign countries, but at that time Thomson's name was included in a list of 5 outstanding American engineers unanimously endorsed by the directors.

THOMSON'S EARLY LIFE

Elihu Thomson was born March 29, 1853, at Manchester, England, to an English mother and a Scotch father. The family came to the United States in 1858, settling in Philadelphia, Pa., where Doctor Thomson attended the public schools. Completing his preparatory education at the age of 11, he had to wait 2 years to meet the minimum age of 13 years required of high school entrants. During this 2-year period, with the encouragement of his parents, he devoted himself to his experiments and his hobbies. He constructed a friction type of electric generator from a wine bottle, and built Leyden jars to be charged by his generator; these and the other similar electrical apparatus of the time were followed by such things as batteries, and electromagnets and telegraph instruments in which the bare wire used for the windings was insulated by the laborious task of winding thread around it by hand. While still a child his interest in astronomy led him to construct his own telescope with the help of a friendly lens maker. In later life he continued the pursuit of this hobby, building powerful telescopes himself and grinding his own lenses.

After he graduated from Central High School early in 1870, he entered a laboratory as an analyst, but was appointed assistant professor of chemistry in the high school later in the same year. In 1876, at the age of 23, he was appointed professor of chemistry in the same school, but he had become deeply interested in the applications of electricity, and in 1880 resigned to devote his entire time to electrical research and development. He always had been fascinated by physical and chemical studies, and especially by electricity.

Possessed of a natural knack for construction and the use of tools, he gave what time he could spare from other duties to making such apparatus as he needed. In this way, before the age of 20, he had built induction coils, electromagnets, cameras, chemical balances, and many other devices. In his early twenties he constructed numerous pieces of scientific apparatus for demonstration and laboratory use, including a compound microscope; also numerous electrical machines and a pipe organ with electrical action for which he made the pipes, windchest, bellows, keyboard, and all other parts.

INDUSTRIAL DEVELOPMENT

When Doctor Thomson resigned his professorship at Central High School in 1880, he took charge of the commercial development of an arc-lighting system for the American Electric Company, a small firm that had been started in Philadelphia in 1879. At the same time E. J. Houston, his colleague at the high school and later a president of the Institute, resigned his teaching position and joined him in the business. Later in the same year the company moved to New Britain, Conn. E. W. Rice, Jr., subsequently a president of the Institute and president of the General Electric Company, accompanied Thomson as an assistant. In 1883 the modest establishment at New Britain was moved to Lynn, Mass., a "Lynn Syndicate," as it was called by Thomson and his associates, having bought control of the American Electric Company. At Lynn the name of the company was changed to the Thomson-Houston Company, and during these pioneer years Doctor Thomson was "electrician" and chief engineer, and many of the fundamentally important inventions upon which the business was established and grew were his. He shunned administrative duties, and the commercial destiny of the company was largely in the hands of Charles A. Coffin.

In 1892, the Thomson-Houston Electric

Company and the Edison General Electric Company were merged to form the General Electric Company. Thomson remained as consulting engineer and director of the Thomson Research Laboratories at Lynn. By his own choice he devoted his time and efforts to research and development rather than to administrative work. Charles A. Coffin became the first president of the new and rapidly expanding company.

Honors Conferred on Thomson

Elihu Thomson probably was the most honored scientist in America. He was acclaimed by several colleges and universities, receiving the honorary degrees of master of arts (1890) from Yale University, doctor of philosophy (1894) from Tufts College, doctor of science from Harvard University (1909) and the University of Manchester (England) (1924), and doctor of laws from the University of Pennsylvania (1924). He was awarded many prizes, medals, and decorations, and had the distinction of being the only man to receive all 3 of the most important scientific medals of Great Britain: the Hughes Medal of the Royal Society, the Kelvin Medal, and the Faraday Medal of the Institution of Electrical Engineers. The Royal Institution of Great Britain elected Thomson an honorary member, the highest scientific honor that Englishmen can confer upon a foreigner. The complete list of awards, decorations, and medals received by him is impressive:

1. **John Scott Legacy Medal, for electric welding, 1888**
2. **Grand Prix, Paris Exposition, 1889**
3. **Appointed officer et chevalier of the Legion D'Honneur, 1889**
4. **Certificate of award of gold medal, Columbian Exposition, 1893; no medal was received**
5. **First prize, Trans-Mississippi and International Exposition, Omaha, Nebr., 1898**
6. **Grand Prix, Paris Exposition, 1900**
7. **Rumford Medal, for electric welding and lighting, 1901**
8. **John Scott Legacy Medal, for constant-current transformer, 1901**
9. **Grand Prize, Louisiana Purchase Exposition, St. Louis, Mo., 1904**
10. **First Edison Medal of the AIEE, 1909**
11. **Elliott Cresson Medal of the Franklin Institute, 1912**
12. **John Fritz Medal, 1916**
13. **Hughes Medal of the Royal Society, London, England, 1916**
14. **Kelvin Medal, 1924**
15. **Franklin Medal, of the Franklin Institute, 1924**
16. **Faraday Medal, Institution of Electrical Engineers, 1927**
17. **Medal of the Verein Deutscher Ingenieure, 1935**

In 1925 Thomson was designated as "father of protective grounding" by a resolution adopted by the Western Association of Electrical Inspectors. He was one of 6 official United States delegates to the chamber of delegates of the electrical congress in Chicago in 1893; president of the International Electrical Congress in St. Louis in 1904; a member of the World Engineering Congress at Tokyo, Japan, in 1929; and a United States delegate to the International Electrical Congress at Paris, France, in 1932. Many technical and scientific organizations including the Institute, had conferred honorary membership upon Doctor Thomson. These were:

1. **Franklin Institute**
2. **Institution of Civil Engineers (Great Britain)**
3. **Institution of Electrical Engineers (Great Britain)**
4. **Royal Institution (Great Britain)**

A photograph showing Doctor Thomson on his eightieth birthday, reading some of the many congratulatory letters that came to him from all parts of the world on that occasion

In Memoriam

ELIHU THOMSON

DR. ELIHU THOMSON, a charter member, the fifth president, and an honorary member of the American Institute of Electrical Engineers, died at his home in Swampscott, Mass., on March 13, 1937, about two weeks before his eighty-fourth birthday.

Beginning his electrical experiments at the age of eleven, when he had completed his preparation for high school but found it necessary to wait two years to meet the minimum age requirement for entrance, he built and operated several types of equipment, and quickly demonstrated his ability in fundamental science and also his remarkable inventive genius. After graduating from the Central High School in Philadelphia and teaching chemistry and mechanics in that school during the next ten years, he resigned in 1880 to devote his entire time to electrical research.

The American Electric Company which he joined soon became the Thomson-Houston Company and the latter merged, in 1892, with the Edison General Electric Company to form the General Electric Company, with which Dr. Thomson was connected until his death.

His more than 700 inventions included many of outstanding importance which added materially to scientific knowledge and laid the foundation for many significant developments in the electrical industry. The combination of marked scientific ability, broad vision, sound judgment and pleasing personality gave him a position of outstanding leadership throughout his long career.

He received the first Edison Medal awarded by the Institute, and received many of the most notable medals in the world, having been the only man to receive all three of England's highest scientific honors, the Hughes, Kelvin, and Faraday medals. He received several high honorary degrees, including Ph.D. ScD., and LLD. He was elected an Honorary Member by the AIEE and several other societies, and received other high honors in the United States and abroad.

Entering the Institute as a charter member, he immediately became active in its affairs, and was a vice-president 1887–89, and president 1889–90. He also rendered valuable services to the Institute as member of various important committees and as its representative in joint activities. He was transferred to the grade of Member in 1891 and to the grade of Fellow in 1913. He was elected an Honorary Member in 1928.

RESOLVED: That the Executive Committee of the American Institute of Electrical Engineers, upon behalf of the Board of Directors and the membership, hereby expresses its keen regret at the death of Doctor Thomson, and its deepest appreciation of his many outstanding contributions to electrical engineering progress, and be it further

RESOLVED: That these resolutions be entered in the minutes and transmitted to his family.

—AIEE Executive Committee, March 25, 1937.

5. Alumni Association of Massachusetts Institute of Technology
6. American Electrotherapeutic Association
7. American Welding Society
8. American Society of Mechanical Engineers
9. Illuminating Engineering Society
10. New York Electrical Society
11. Engineers' Club, New York, N. Y.
12. Western Association of Electrical Inspectors
13. New England Roentgen Ray Society
14. American Institute of Electrical Engineers

OUTSTANDING ACCOMPLISHMENTS

Perhaps the first great contribution to electrical engineering made by Elihu Thomson was his invention, in about 1879, of the 3-coil dynamo with its automatic regulator and other novel features, which formed the basis of the first commercially successful lighting system. This was manufactured by the Thomson-Houston Company in the early 1880's and quickly found its place not only in the United States, but also in several European countries. The machine was entirely automatic in its operation, and was so adjusted that it could maintain constant regulation of a system of many electric arcs, regardless of the number of arcs that might be turned on or off. The need for such a regulator and its general nature were suggested to him by his earliest serious electrical studies, which concerned the relations between the voltage and current in an electric arc, and which led him to the discovery that as the current increases the voltage decreases. This relation accounted for the instability of the arc and indicated what characteristics the dynamo should have. This 3-coil dynamo was a d-c machine, for at that time direct current was more easily handled than was alternating current, and had certain advantages for arc-lighting purposes. The same machine, however, with different connections, constitutes the 3-phase generator that is so important in present electric power installations, and was so represented by Thomson in his original patent application.

While he was working on his arc-lighting system, Thomson heard that Edison was tinkering with an incandescent lamp. Accordingly he went to Menlo Park to discuss the matter with Edison, who gave him a model of the lamp. This model subsequently was dissected by Thomson and Houston, with the decision that it never would amount to anything.

LIGHTNING PROTECTION—MAGNETIC BLOWOUT

About 2 years later, in 1881, he invented another important electrical device: the magnetically operated lightning arrester. Although this arrester was created for the particular purpose of protecting his arc-light systems from lightning, it was the invention of a fundamental method of breaking electrical circuits that has found numerous applications, one of the most important of which was by Doctor Thomson himself in control contactors for electric cars and trains. The device consisted of an insulator so placed between the poles of a magnet, and the whole so arranged with respect to the contacts or electrodes, that any arc forming was forced by the magnetic field to elongate itself to the breaking point, thus quickly and effectively interrupting the circuit. This principle is of as much importance today as it was then, for it is the foundation of several modern systems of switching large currents.

POWER TRANSMISSION

In those very early days of electrical engineering, long before the importance of electric power transmission and distribution was realized generally, Thomson devised the now commonly used method of transmitting electrical energy, stepping it down from high voltage with the aid of a local transformer for local consumption. This was set up as a working model for demonstration at the Franklin Institute in Philadelphia in 1879. A patent was applied for in 1885, and after a strenuous period in the patent office a fundamental patent for multiple-arc distribution systems with transformers was granted in 1902. During this same time Thomson developed and patented the procedure of grounding the secondary of the transformer as an additional safety measure for high-voltage operation. A notable characteristic of Doctor Thomson is indicated by his advice to the General Electric Company that this patent should be dedi-

Future AIEE Meetings

North Eastern District Meeting
Buffalo, N. Y., May 5–7, 1937

Summer Convention
Milwaukee, Wis., June 21–25, 1937

Pacific Coast Convention
Spokane, Wash., Aug. 30–Sept. 3, 1937

Middle Eastern District Meeting
Akron, Ohio, Fall 1937

cated to the public, because no patent or invention dealing with public safety should be restricted or made unavailable for general use.

Developments on the Transformer

In the further development of a-c machinery, he invented the constant-current transformer and the induction regulator, in which a movable secondary or primary coil could be adjusted automatically to give constant-current output. For the purpose of increasing the power capacity of transformers, he proposed in 1887–89 the use of oil for cooling and for insulation purposes, and further called attention to the deleterious effect of moisture in the oil.

Resistance Welding—Repulsion Motor

One of the most important of Thomson's contributions to industry was his discovery of the principles and development of the resistance process of electric welding, whereby the welded surfaces were fused and united by the heat produced by the resistance in the contact between them. Although Elihu Thomson was not the first to utilize the electric arc in welding, the fundamental Demeritens patent was bought by the Thomson Electric Welding Company on Thomson's advice and, had arc welding developed within the life of the patent, that company would have controlled the arc- as well as the resistance-welding art.

Another of Thomson's most fundamental discoveries was the principle of dynamic repulsion between a primary and a secondary coil, which he demonstrated by simple experiments. A vertical iron core was wound with a coil through which an alternating current could be passed. The core projected above the coil into a jar of water. Fitting loosely around the core was a second small coil, free to slip up and down the core in the water, and supporting by its terminals an incandescent lamp. When an alternating current was sent through the primary coil, a current was induced in the movable secondary coil, which lighted the lamp and at the same time raised the coil against the force of gravity high up in the jar of water. This scientific observation subsequently was developed by Thomson into an a-c repulsion motor.

Meters—High-Frequency Apparatus

During the years 1885–95 Doctor Thomson was busily engaged in the development of electric meters, especially recording wattmeters. For his wattmeter he was awarded the Grand Prix of the Paris Exposition at a competition held after the exposition in 1889.

As early as 1890, and continuing intensively for several years thereafter, he conducted a series of experiments on high-

A collection of the medals and decorations conferred upon Elihu Thomson

Top row (left to right): John Scott Legacy Medal, for constant-current transformer, 1901; Franklin Medal, of the Franklin Institute, 1924; Faraday Medal, Institution of Electrical Engineers, 1927; John Fritz Medal, 1916; and John Scott Legacy Medal, for electric welding, 1888

Middle row (left to right): Grand Prix, Paris Exposition, 1900; Elliott Cresson Medal of the Franklin Institute, 1912; Kelvin Medal, 1924; Hughes Medal of the Royal Society, London, England, 1916; and Grand Prix, Paris Exposition, 1889

Bottom row (left to right): First Prize, Trans-Mississippi Exposition, Omaha, Nebr. 1898; Edison Medal, 1909: Legion D'Honneur, officier et chevalier, 1889; Rumford Medal, for electric welding and lighting, 1901; and Grand Prize, Louisiana Purchase Exposition, 1904

A gold medal was awarded to Doctor Thomson at the Columbian Exposition, in 1893, by certificate of award, but no medal was received; he also received in 1935 the medal of the Verein Deutscher Ingenieure, which is not shown here frequency alternating currents, building the foundation for many of the developments in radio and other high-frequency applications in use today. He constructed one of the first high-frequency dynamos, if not the first; a machine operating at frequencies of from 30 to 40 times as great as any previously built. In conjunction, he designed some of the earliest high-frequency transformers. While Thomson was working in this field he discovered a method of producing alternating currents of still higher frequencies from a d-c arc by shunting the arc with inductance and capacitance. This interesting method of producing alternating currents later was applied to radiotelegraphy by Poulsen, and therefore is generally known as the Poulsen arc. Thomson also discovered that the insulating power of oils at these high frequencies is much greater than at ordinary commercial frequencies, if the insulating power is measured in terms of the path through which the arc passes.

Incidentally, Thomson is credited with having discovered the principle of the tuned electric circuit, and with having been the first to use the method in electrical communication. This was done very early in his career, while he was still a professor at Central High School, in performing some experiments in wireless signaling that preceded the famous experiments of Hertz by about 12 years.

Immediately following the announcement of the discovery of Roentgen rays, Doctor Thomson began a series of experiments and developments in connection with X rays. The foundation for this work had been laid by his previous experiments on electrical discharges through gases at low pressures, and led to the first application of stereoscopic methods in X-ray technology only one year after Roentgen rays themselves had been announced. This work led to various practical improvements in the design of X-ray tubes. Thomson also took an interest in the physiological effects of X rays.

Elihu Thomson also was active outside the domains of electrical research. Working with Houston, while they were at Central High School, he perfected his centrifugal machine for the separation of liquids of different densities, the forerunner of the widely used cream separator and the laboratory and commercial centrifuge. He also devised the fluid-pressure engine and the fused-quartz mirror for astronomical telescopes. In his own name he held more than 700 American patents.

THOMSON THE MAN

In his private life as a citizen, as well as an inventor, Elihu Thomson endeared himself to his neighbors and his fellow workmen and always was considered to be a wise counselor in civic affairs. Even outside his laboratories he was always engaged in some research project as a hobby. A lifetime hobby was astronomy, in which he was active as an amateur from an early age. He also was interested in microscopes, color photography, and in building and playing pipe organs. He had a host of friends, not only in the United States, but also in Europe.

His aspect of life is characterized by his own words "No greater joy has come to me than the joy of accomplishment. Then too, I have had the satisfaction of aiding in giving employment to large numbers of intelligent men and women."

Doctor Thomson was a member of many organizations in addition to those that had awarded him honorary memberships, including:

1. American Academy of Arts and Sciences (fellow and member of the Rumford committee)
2. American Association for the Advancement of Science (fellow)
3. American Astronomical Society (member)
4. American Chemical Society (life member)
5. American Electrochemical Society (member)
6. American Mathematical Society (member)
7. American Optical Society (member)
8. American Philosophical Society (fellow and past-president; also a past member of the council)
9. American Physical Society (fellow and life member)
10. Pi Gamma Mu, national science honorary society (life member)
11. British Association for the Advancement of Science (life member)
12. Engineers' Club of London, England
13. Société Française des Electriciens (member)
14. Commercial and Merchants Club of Boston, Mass. (member and past-president)
15. Engineers' Club of Boston (life member)
16. Boston Press Club (life member)

and 22 other societies and clubs of local, national, and international character.

Doctor Thomson was particularly interested in educational work. His vast store of experience and knowledge always was at the disposal of his younger, less experienced associates, among whom he was noted for his ability to explain the most abstruse subjects in simple, understandable language. He was affectionately known to them as "the Professor," a simple "friendly" title that he strongly preferred in spite of his many degrees. He was a life member of the Corporation of Massachusetts Institute of Technology, a member of the executive committee of the corporation, and twice served as its acting president.

For many of its most fundamental contributions—technical, ethical, and humanistic—the profession of electrical engineering is indebted to Elihu Thomson.

THOMSON AS SEEN BY SOME INSTITUTE LEADERS

Arthur E. Kennelly, president 1898–1900—I had the privilege of knowing the late Professor Thomson for many years. He was endowed with great abilities as an engineer, inventor, researcher, and teacher. His special fields of work were in applied physics, chemistry, and mechanics. He was a pioneer in electric power transmission and distribution, as well as in electric welding, an art which he founded and highly developed. He was an excellent designer and constructor of electric machinery and apparatus. Many of the machines and instruments used in the early days of the electric power industry were constructed under his design and superintendence. At one time he constructed a 25-centimeter telescope, lenses and all, with his own hands. He introduced and developed the existing prevalent types of electric motor-driven energy meters, registering in kilowatt-hours.

He was a tireless scientific worker from early boyhood. At 17 years of age he was assistant professor of chemistry and at 22 was professor of chemistry in the Central High School of Philadelphia, where, in his leisure time, he made important inventions in electric power transmission.

He never allowed any of his time to be wasted. His was a kindly, engaging, and stimulating, personality. As a leader in electrical engineering he was admired and esteemed by thousands.

Charles F. Scott, president 1902–03—As I recall Professor Thomson, several specific incidents come to mind, trivial perhaps, but characteristic.

One afternoon some 12 or 13 years ago we had been in conference in Boston on some committee matter and found ourselves with a couple of hours to spare. We strolled about the city as he led the way to some particular photographic shops, in his search for films for color photography in which he took great interest. I was never more impressed with the great simplicity and ease of his manner and conversation.

To me, Professor Thomson always was a great electrical pioneer. Later I had met him, principally in AIEE activities. But, in strolling with him through the streets of Boston, I realized that my once mystical hero was very human; in simple companionship, he even insisted on accompanying me to my place of departure.

On the occasion of the celebration of his eightieth anniversary held in 1933 at Massachusetts Institute of Technology, I asked him what it was at the centennial exposition in Philadelphia in 1876 that aroused his interest in electricity. Immediately a smile came over his face and with a twinkle in his eye he said, "I will tell you. There was a Gramme dynamo there from France which operated one arc lamp, and there was another dynamo for electroplating, and another which lighted the lamp on the top of the building." This memory meant a great deal to him as it later on shaped his whole career.

He told me also an interesting incident "The Rhumkorff coil uses a low-voltage current for producing a very high voltage. I wondered if the process could be reversed and the high voltage current in the fine winding would produce a current in the heavy winding. I was fearful of the results and put off the experiments until I had a coil of my own. I placed the ends of the heavy terminals close together and observed carefully when the Leyden jars were discharged through the fine wire coil. There was a flash and when I attempted to separate the terminals I found them solidly welded together. That was the beginning of my work in electric welding."

His curiosity, his readiness to experiment, his observation, and his practical deductions from his experiments were the beginning of a new art.

And it seems to me that these qualities of simplicity and modesty, and his following along the lines prompted by his curiosity and interest, indicate qualities which were inherent in the man and have influenced his whole career.

Dugald C. Jackson, president 1910–11—Elihu Thomson was great as an engineer, as a scientist, and as a citizen; and in each category he has received deservedly high recognition. I first met him when he was 35 years old and I was 21, and the impression of his fascinating enthusiasm for the development of electrical engineering and his fertile approach to difficult problems of experimental science has never left me. It has seemed to me that those qualities in Thomson have equally stirred others and led to the wish to honor him that has been displayed internationally.

Being, by intellectual nature, a great inventor, Thomson directed his qualities into human service, and the world is indebted extraordinarily to him for his productions. At least one of his original inventions, electric welding, has become a great industry of itself as well as contributing advantages to many industries. Numerous others of his productions have widely influenced industry and contributed to human comfort. The death of Thomson takes a great man from electrical engineering and a great citizen from the nation.

Gano Dunn, president 1911–12—Elihu Thomson's magnificent scientific and engineering accomplishments have made history. To me his personal influences was as great as his intellectual influence. He always had in mind the inventor, the engineer, the student, as well as the invention, the design and the study. This will forever cause him to be rated as one of our greatest teachers as well as one of our greatest engineers and scientists.

It was to him I early owed recognition that all engineering, notwithstanding its tremendous economic involvements, rests inseparably upon science. His lectures and papers were marvels of exposition. A talk with Elihu Thomson invariably stimulated thought and fired ambition.

His methods of work and qualities of character formed the careers and won the undying affection of large numbers of the generation of engineers who now mourn his loss.

Frank B. Jewett, president 1922–23—Appraisal of Elihu Thomson and his contributions to the advancement of electrical engineering in the light and power field can best be made by those who were his close associates in the many sectors of it which were enriched by his scholarly mind.

Outside the field of our common interest in the welfare of the American Institute of Electrical Engineers, in which our association commenced, my long and close friendship with Dr. Thomson has hardly been involved with things electrical. It has been concerned mainly with matters of general scientific interest and in the problems which came to us as fellow members of the Corporation of Massachusetts Institute of Technology.

Above all other things, however, it has been as an esteemed friend that I have known, admired, and loved Doctor Thomson. His versatile and cultured mind, his simplicity, and his joy in the simple worth-while things of life, which did not diminish with the years, made him a friend to be cherished.

Quite outside the boundaries of his professional life, his death will deprive the world of one of its choice spirits.

Elihu Thomson in his laboratory, studying the heavens through his telescope. Astronomy was his life-long hobby

H. P. Charlesworth, president 1932–33—Doctor Thomson's investigations and inventions contributed enormously to the advance of all the engineering arts. However, his contributions went further than these individual activities. In addition to publishing his results and methods, his enthusiasm and technique were passed on to hundreds of engineers, first as a professor, later as a director of the laboratories which bear his name, and finally as a great leader in his profession. His fruitfulness was shared with others whom he had trained and inspired. His whole life was indeed in accord with and greatly contributed to the highest ideals of the engineering profession. It is not surprising, therefore, that his name is among the illustrious group who were the charter members of the American Institute of Electrical Engineers which ever is endeavoring to perpetuate these high ideals.

A. M. MacCutcheon, president 1936–37—One of my greatest regrets is that I did not have the privilege of a close personal acquaintance with Doctor Elihu Thomson, but I am fortunate in having met him. His writings have been an inspiration to me even as far back as my student days.

His deductions, his inventions, and his achievements form a cornerstone in the theoretical structure which represents the engineering knowledge of our time.

His modesty, his cheerful optimism, his breadth of vision, his clear thinking, and his indomitable spirit formed a pattern which all engineers may well emulate.

He was a charter member of the American Institute of Electrical Engineers and its fifth president. We who have followed in his footsteps, looked upon him as an inspiration, a valued counselor, a guiding light.

ELIHU THOMSON AS SEEN
BY SOME INDUSTRIAL ASSOCIATES

Owen D. Young, chairman, General Electric Company—Mr. Thomson was one of the few great pioneers in the electrical field who had the rare good fortune to see his vision become a reality and to receive the appreciation of a justly grateful world for his contribution to the health and happiness of people everywhere. The General Electric Company was always proud of his intimate association with it.

Willis R. Whitney, vice-president, General Electric Company—Professor Thomson was one of the leaders who helped in the establishment of the Northeastern Section of the American Chemical Society back in '97 or '98. We New England chemists knew him as an expert in our field, just as the electrical engineers recognized him as preeminent in their field, and the mechanical engineers as a leader in theirs. Astronomers also knew that he was of their group. He was an all-round scientist.

When the General Electric Company offered me the research work at Schenectady, I was in doubt as to my fitness and as to the quality of the opportunity until I hurriedly consulted "the Professor." He was very kind, as always, and was quite clear that the opportunity offered me was a great one. So I owe a large part of the satisfactions I have enjoyed during the past 36 years to Professor Thomson's kindly interest. Through those years my admiration and affection for him steadily increased, and in his death I feel a great personal loss.

Gerard Swope, president, General Electric Company—Since the very beginning, Professor Thomson was associated with the General Electric Company and its predecessor bearing his name, the Thomson-Houston Company. His accomplishments for these companies and many others throughout the world bearing his name and for the entire electrical industry were many and conspicuous.

His interest in research, his enthusiasm for new ideas, and the advancement of young engineers continued almost to the day of his passing. His memory will long be cherished by those who knew him, and he leaves a fine tradition and inspiration for those who follow him.

William D. Coolidge, director, General Electric Research Laboratory—In the death of Professor Thomson, the General Electric Company has suffered a great loss. Its earliest products were for the most part the offspring of his brain. Great in engineering and invention, he played a most important rôle in the early development of the electrical art. He was a pioneer in arc lighting, was the father of electric welding, devised the first commercial recording wattmeter, and produced by the score the various devices needed for making electric generation and distribution reliable and safe.

He was a true scientist, and by example and precept established the tradition of scientific research in the General Electric Company. When the research laboratory of the company was founded, he served on its advisory council, and, by his experience, wisdom, and fertility in ideas, was of great help to the laboratory in its early years.

His breadth of knowledge, mental alertness, and originality made association with him delightful and stimulating, while his kindliness and simple sincerity won the affection of all who knew him. I was privileged to know him well, and I feel the loss of a great and good friend.

Karl T. Compton, president, Massachusetts Institute of Technology—In his own character and in his great achievements he was one of the truly great men of his century. In all the years of his interest in the Institute [MIT], he displayed a loyal and active faith in the social values of technological education.

Professor Thomson's loss to this institution and all others would be irreparable were it not for the fact that his nobility of character will remain as a lasting inspiration, and his scientific achievements will continue permanently to confer immeasurable benefits to the world.

Lightning Reference Book To Be Issued Soon

Culminating more than 2 years of work carried on by the lightning and insulator subcommittee of the AIEE power transmission and distribution committee, the AIEE Lightning Reference Book is scheduled to be issued in July.

Lightning and its effect upon electric power systems and apparatus have been under investigation for more than 20 years during which many articles of interest and value have been published in the technical literature. Heretofore this extensive literature has been available principally only through library research. Now, recognizing the value of a conveniently bound volume containing the full reproductions of texts, illustrations, and tabulations of all important material that has been published on the subject of lightning, the subcommittee has completed the selection of just such material for just such a handy reference volume.

The Lightning Reference Book will be about the size of the current annual volumes of AIEE TRANSACTIONS and similarly bound in durable green cloth. It will contain some 1,550 pages, $8^{1}/_{2}$ by 11 inches in size, in which will be reproduced in full some 230 technical papers and articles selected by the subcommittee from the technical press of the past 18 years for their important and practical utility to all those in any way interested in the study of, or the protection against, lightning

A comprehensive subject and author index will facilitate the ready reference use of the volume and, for those who may wish to carry their pursuit further, 200 additional technical papers and articles of a supplemental nature not included in the volume will be fully covered in the indexes.

The announced price of the Lightning Reference Book is $6.00 to members and $7.50 to nonmembers, plus postage in either case (10 pounds shipping weight).

ADVANCE ORDERS REQUIRED

A limited edition only will be issued. The actual number of volumes to be published will be governed by the number of advance orders on file at AIEE headquarters, 33 West 39th Street, New York, N. Y. by May 15, 1937 (with reasonable allowance for overseas mail).

The several hundred advance orders that have been on file the past year have made possible the prosecution of this project to successful conclusion with publication now imminent. All persons wishing to increase standing orders, or to place orders, must do so immediately to be assured of receiving the volume.

Further details and a convenient order coupon are given on page 4 of the advertising section of this issue.

Membership—

Mr. Institute Member:

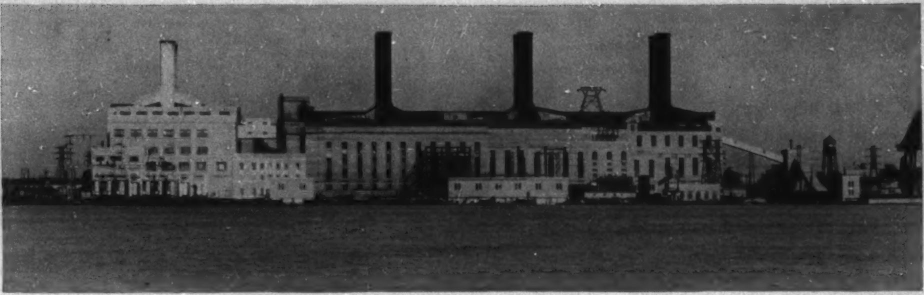
Have you finished reading that recently distributed pamphlet entitled "Membership in the American Institute of Electrical Engineers"? It does a fine job of sketching the activities of the Institute—don't you agree?

Please do not forget to pass it along to some non-member who is eligible for membership. Also, if you can interest him in becoming a member, recommend him by using the stamped and addressed card furnished with the pamphlet. He will receive application blanks and necessary information promptly.

Your Membership Committee thanks you sincerely for the very good co-operation you have given it throughout the year. With your continuous service, we shall surely reach our goal of twenty-five per cent more applications than last year.

G A Kositzky

Chairman
National Membership Committee



Huntley stations of the Buffalo General Electric Company

North Eastern District Meeting and Student Branch Convention

THE annual meeting of the North Eastern District of the AIEE and student Branch convention will be held in Buffalo, N. Y., from Wednesday to Friday, May 5–7, 1937. The meeting headquarters will be in the Hotel Statler. Buffalo "the gateway to the west" with its many diversified industries makes an ideal convention city and the local committee has taken full advantage of the situation and arranged a very attractive program. Thus there is a trip to the new $22,000,000 hot and cold strip mill of the Bethlehem Steel Company, Huntley stations 1 and 2, some of the hydroelectric stations at Niagara Falls, the Ford Motor Company's plant, and several of the other industries, not to mention a very attractive trip for the ladies, including the marvelous spectacle of Niagara and its color illumination. Entertainment has been arranged for the evenings and men prominent in Institute affairs are on the program.

Table I—Hotel Rates

Hotel and Location	Room Capacity	Single Without Bath	Single With Bath	Double Without Bath	Double With Bath	Twin
Arlington, 136 Exchange	150	$1.50	$2.00 up	$2.50 up	$3.50 up	$4.00 up
Buffalo, Swan and Washington	450		2.00 up		4.00 up	4.50 up
Fairfax, 715 Delaware	400		2.50 up		4.50 up	5.50 up
Fillmore, 207 Delaware	60		1.75 up		3.00 up	3.50 up
Ford, Delaware and Cary	750	1.50 up	1.50 up	2.50 up	3.00 to 4.00	3.25 to 4.00
Graystone, Johnson Park	150	1.50 up	2.00 up	2.50 up	3.00 up	3.00 up
Lafayette, Lafayette Square	420		2.50 up		4.50 up	4.50 up
Lenox, 140 North St	200		2.00 up		3.50 up	4.00 up
Men's, Genesee and Pearl	283	0.75 to 1.25		1.50 & 2.00	(Master bathroom on each floor)	
Statler, Niagara Square	1,100		3.00 up		5.00 up	6.00 up
Stuyvesant, 245 Elmwood	450		2.00 up		3.00 up	4.00 up
Touraine, Delaware	300	1.75	2.00 up	3.00 up sharing bath	3.50 up	4.50 up
Westbrook	312		2.50 up		4.00 up	6.00 up twin 3-room suite

Registration will take place in the Hotel Statler from 9:00 a.m., Wednesday, May 5.

Technical Sessions

The opening session will consist of an address of welcome by A. C. Stevens, Institute vice-president for the North Eastern District, which will be followed by a series of papers of outstanding interest to all who are connected with the central station industry. These papers include the latest information in the field of lightning investigations on transmission lines, the application of automatic oscillography, operating performance, research, and testing.

On Thursday, May 6, a general session will be held at 9:30 a.m. which will be opened with a greeting by President MacCutcheon. This session will feature conductor vibration studies illustrated by motion pictures, surveying telephone service requirements, and design trends in steel mill electrification. In the afternoon the electrical features of the new Bethlehem 72-inch strip mill will be described by F. D. Egan and his talk will be followed by a trip to the plant. On Thursday morning a student technical session will be held at which papers will be presented by the students.

Entertainment

On Wednesday evening a talk and demonstration on "Fiber Glass" will be given by L. W. W. Morrow, general manager of the fiber glass department of the Corning Glass Works. All who know Mr. Morrow and his ability to give an interesting talk will look forward to a very enjoyable evening. On Thursday evening directly following the informal dinner another very instructive, interesting talk and demonstration will be given. The subject will be "Kodachrome Colored Film" by L. D. Mannes, co-inventor, of the Eastman Kodak Company. After the lectures dancing also may be enjoyed in the hotel.

Women's Entertainment

In addition to the foregoing entertainment the following has been specially arranged for the women guests of the Institute. Buffalo is a large, smartly metropolitan city, possessing beautiful parks and suburban areas.

Wednesday, May 5

A trip to the incomparable Niagara Falls. Leaving at 11:00 a.m., the party will cross the Peace Bridge and drive down the beautiful Canadian Boulevard. After luncheon, there will be an inspection trip of the Falls and the Niagara Rapids, followed by dinner in the modern General Brock Hotel, from the roof garden of which can be seen another interesting view of the cataract. At 8:00 p.m. the illumination takes place and to see the mighty waterfall in the play of clear and colored lights is a sight never to be forgotten.

Thursday, May 6

A luncheon at the Hotel Statler, followed by a fashion show presented by one of Buffalo's smartest shops.

Inspection Trips

Buffalo and its environs have over 500 diversified industries. The committee has

Program

Daylight Saving Time

For the papers that have been published in ELECTRICAL ENGINEERING reference to the issue and page is given.

Wednesday, May, 5

9:00 a.m.—Registration

10:00 a.m.—Opening Session

Address of Welcome, A. C. Stevens, vice-president, North Eastern District, AIEE.

LIGHTNING CURRENTS IN 132-KV LINES, Philip Sporn and I. W. Gross, American Gas & Electric Company. February, pages 245–52, 259–60

PROBABLE OUTAGES OF SHIELDED TRANSMISSION LINES, S. K. Waldorf, Pennsylvania Water & Power Company. Scheduled for May issue

SPECIAL USES FOR THE AUTOMATIC OSCILLOGRAPH, G. A. Powell and R. E. Walsh, New York Power & Light Corporation. April, pages 438–40, 476–7

2:00 p.m.—General Session

*THE OPERATING PERFORMANCE OF VARIOUS RELAY APPLICATIONS, George Steeb and L. J. Audlin, Buffalo, Niagara, and Eastern Power Corporation.

*THE OPERATING PERFORMANCE OF HUNTLEY STEAM STATION, J. M. Geiger (electrical) and Donald Scranton (mechanical), Buffalo General Electric Company.

*RESEARCH AND TESTING IN A LARGE ELECTRIC UTILITY, (*A*) by W. F. Davidson, Brooklyn Edison Company, Inc., and (*B*) by W. P. Dobson, Hydro Electric Power Commission of Ontario.

8:00 p.m.—Talk and Demonstration

FIBER GLASS, L. W. W. Morrow, Corning Glass Works.

Thursday, May 6

9:30 a.m.—General Session

Greeting, A. M. MacCutcheon, president AIEE.

*EXPERIMENTAL STUDY OF DANCING CABLES, D. C. Stewart, Buffalo, Niagara and Eastern Power Corporation. Illustrated by motion pictures of dancing when the cable was coated with water to simulate an ice formation.

*SURVEYING TELEPHONE SERVICE REQUIREMENTS FOR LARGE USERS, R. E. Corey, New York Telephone Company.

*DESIGN TRENDS IN STEEL MILL ELECTRIFICATION, L. A. Umansky, General Electric Company.

2:00 p.m.—Special Address

ELECTRICAL APPLICATION—BETHLEHEM 72-INCH STRIP MILL, F. D. Egan, Bethlehem Steel Company.

3:00 p.m.—Inspection Trip

Bethlehem Steel Company's 72-inch new strip mill. Note: Number limited and women are excluded. Everyone must arrive by bus in the party and cameras are prohibited. Nominal charge for busses to and from the hotel.

7:00 p.m.—Informal Dinner

8:30 p.m.—Talk and Demonstration

KODACHROME COLORED FILM, L. D. Mannes, co-inventor, Eastman Kodak Company.

Friday, May 7

9:30 a.m.—Student Technical Session

2:00 p.m.—Inspection Trip

Huntley stations No. 1 and No. 2 of the Buffalo General Electric Company; number will be limited and a nominal charge will be made for busses to and from the hotel.

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* These papers are scheduled for presentation, but they have not been accepted for publication at the time of going to press.

judiciously selected the following trips, some of which are optional in the short time available.

1. Bethlehem Steel Company's New $22,000,000 Hot and Cold Strip Mill

The number to be accommodated is of necessity limited and all people must arrive by bus with the party, which will not include any ladies. Anyone arriving by private car will not be admitted. The carrying of cameras or taking pictures is not permitted. Nominal charge for busses to and from the hotel.

2. Huntley Stations No. 1 and No. 2 of the Buffalo General Electric Company

The number is of necessity limited. Nominal charge for busses to and from the hotel.

3. Other Trips of Interest.

The number which can be accommodated on some of them is of necessity limited.

A. Niagara Falls Power Company—(1) Adams and Schoellkopf stations; (2) Harper and Gibson substations.
B. Distribution system of Buffalo General Electric Company (Network and Automatics).
C. Local plants of New York Telephone Company.
D. Variable-ratio frequency changer at Lockport, N. Y.
E. Spaulding Fiber plant, Military Road.
F. Remington Rand plants.
G. Albright Art Gallery.
H. Ford Motor Company's plant.
I. Modern broadcasting.
J. Museum of Science.

Industrial plants near Buffalo include:

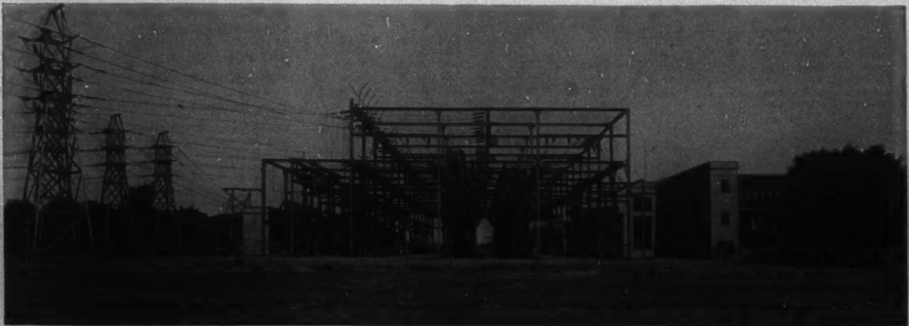
Lapp Insulator Company at LeRoy, N. Y.—50 miles
Porcelain Insulator Company at Lima, N. Y.—65 miles
Corning Glass Company at Corning, N. Y.—125 miles

SPORTS

Golfing in this region is not usually much of a sport until along about Decoration Day. However, weather permitting, the committee will be very glad to furnish the necessary cards so that anyone wishing to play can do so at any course in western New York State.

REGISTRATION

Members who plan to attend the meeting should register in advance by mail. Advance registrations should be sent to George M. Pollard, chairman, registration com-



Harper substation of the Niagara Falls Power Company

Adams station of the Niagara Falls Power Company at Niagara Falls, N. Y.

mittee, Buffalo General Electric Company, 39 East Genesee St., Buffalo, N. Y. Registrations should be completed on arrival at headquarters in the Hotel Statler. A registration fee of $2 will be charged all nonmembers except Enrolled Students and the immediate families of members.

HOTELS

Members should make room reservations by writing directly to the hotel of their preference. For convenience the rates of the headquarters hotel, the Statler, as well as the rates of a number of the other hotels are listed in table I.

RULES ON PRESENTING AND DISCUSSING PAPERS

At the technical sessions, papers may be presented in abstract, 10 minutes being allowed for each paper unless otherwise arranged or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion.

Any member is free to discuss any paper when the meeting is thrown open for general discussion. Usually 5 minutes is allowed to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be permitted to have a somewhat longer time.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser is to step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussions to be considered for publication should be typewritten (double spaced) and submitted in triplicate to C. S. Rich, secretary of the technical program committee, AIEE headquarters, 33 West 39th St., New York, N. Y., on or before May 21, 1937. Discussion of addresses and papers which is not for publication need not be submitted for consideration.

COMMITTEES

District Meeting Committee: A. C. Stevens, vice-president, North Eastern District, *chairman;* R. G. Lorraine, secretary-treasurer, North Eastern District, *secretary;* F. N. Tompkins, *chairman*, committee on student activities, North Eastern District; N. E. Brown, R. F. Chamberlain, C. L. Dawes, E. D. Lynch, K. B. McEachron, and J. L. Scanlon.

General Committee: E. S. Bundy, *chairman;* T. J. Brosnan, R. T. Henry, Cromwell McIntosh, and H. M. Sharp.

Program Committee: R. W. Graham, *chairman;* J. F. Oehler and T. O. Zittel.

Registration Committee: G. M. Pollard, *chairman;* J. N. Ewart and J. M. Pfohl.

Ladies Committee: Miss Laura Rischman, *chairman;* Miss Muryle Baker, Miss Nora Haun, and Miss Maryon Ingham.

Dinner Committee: D. C. West, *chairman;* E. A. Brown, H. L. Randall, and T. J. Woth.

Inspection Committee: George Eighmy, *chairman;* C. H. Lockwood and H. L. Townend.

Publicity Committee: N. A. Brown, *chairman;* A. D. Gibson and W. J. Thompson.

Transportation: Clair Gaylord, *chairman;* E. J. Rahill and W. J. Schnautz.

Printing: Melvin Brown, *chairman;* F. L. West and G. A. Zehr.

Canadian Engineers to Celebrate Semicentennial

The Engineering Institute of Canada is planning to celebrate its fiftieth anniversary at a semicentennial meeting to be opened in Montreal on June 15, 1937. The organization, which was formed in 1889 as the Canadian Society of Civil Engineers, now embraces the professional interests of engineers of all branches. There are some 4,500 members, including over 400 outside of Canada.

It is desired that the anniversary meeting may be the means of bringing about closer acquaintances between engineers in the United States and Canada. The principal functions of the meeting are to be in the Windsor Hotel, June 15 to 17 inclusive. Further information may be obtained from the headquarters of the organization at 2050 Mansfield Street, Montreal.

AIEE Summer Convention Features of General Interest

Internationally known industrial plants in the Milwaukee metropolitan area will open their gates to convention visitors during the AIEE summer convention, to be held in Milwaukee, Wis., June 21–25, 1937, with headquarters in the Schroeder Hotel. Trips through a number of such plants are being arranged by the inspection trips committee, of which S. H. Mortensen of Milwaukee is chairman.

Present plans call for the holding of technical sessions of the convention in the mornings, leaving the afternoons free for special inspection tours, sightseeing trips, and sports. The inspection trips are being planned with the view of providing interesting diversion as well as technical and scientific information.

CONVENTION SESSIONS

Tentative arrangements are being made to hold 10 technical sessions and 1 general session designed to interest a great many members. This session will be in 2 parts, which will not be in parallel with any of the other sessions, to permit general attendance. The first part will consist of an address by a prominent speaker, which will have to do with engineering and economics. The second part of the session will consist of a discussion of the topic "how can institute programs be made of greatest value to the membership." The subject will be introduced by men invited to prepare brief statements by the special committee on Institute activities. The 10 technical sessions are as follows: electrical machinery, power transmission, vibration and balance, education, instruments and measurements, protective devices, general power applications (control), selected subjects, research, and production and application of light. The program will be further broadened by technical conferences on other subjects which will be arranged later.

INSPECTION TRIPS

Among the large industrial firms with whom inspection visits have tentatively been arranged are the following:

Allis-Chalmers Manufacturing Company; power, electrical, industrial, and agricultural equipment.

A. O. Smith Corporation; automobile frames and parts, welded pipe, pressure vessels, glass-lined storage tanks, and steel barrels.

Harnischfeger Corporation; large cranes, hoists, and excavators, and electric welders.

Globe Union, Inc.; storage batteries, radios, and roller skates.

Joseph Schlitz Brewing Company; beer.

Milwaukee Electric Railway and Light Company; as announced in the February issue of ELECTRICAL ENGINEERING, opportunity will also be provided for a trip through the new Port Washington power plant. This station holds the world record for economy of operation in steam generating stations, having generated 382,863,218 net kilowatt-hours in 1936, with an average coal consumption of 10,954 Btu per kilowatt-hour.

National and District Prizes Available for Technical Papers

ALL members and Enrolled Students who have presented papers at Institute meetings, as stipulated and otherwise in accordance with the following "Conditions of Awards," are eligible under rules adopted by the board of directors for one or more of the established national and District prizes.

These rules have recently been revised by actions of the board of directors. A new prize in each of the geographical Districts, to be known as "the District prize for graduate paper" has been established. In the future the award of this prize as well as the national and District prizes for Branch paper will be on the basis of presentation during the academic (college) year, July 1 to June 30, inclusive, rather than on the basis of presentations during the calendar year.

Excerpts of the rules as revised fully describing each prize and stating the conditions of awards, when and where the papers should be submitted for consideration, are given in the following paragraphs. However, the changes in these rules explained in the preceding paragraph are not to be applied retroactively and they do not pertain to the 1936 papers now under consideration. The winners of every prize will each receive a certificate of award but by action of the board of directors the only cash award for 1936 papers will be $25 for the "District prize for Branch paper" in each geographical District. When papers are written jointly the cash awards shall be divided and a certificate shall be issued to each author.

National Prizes

Conditions of Awards

1. The national best paper prize in each of the 3 classes namely, engineering practice, theory and research, and public relations and education, may be awarded for the best original paper presented at any national, District, or Section meeting of the Institute, provided the author, or at least one of coauthors, is a member of the Institute.

2. The national prize for initial paper may be awarded for the most worthy paper presented at any national, District, Section, or Branch meeting of the Institute, provided the author or authors have never previously presented a paper which has been accepted by the technical program committee, and the author, or at least one of coauthors, is a member of the Institute or is a graduate student enrolled as a Student of the Institute.

3. The national prize for Branch paper may be awarded for the best paper based upon undergraduate work presented at a Branch or other Student meeting of the Institute, provided the author or authors are Enrolled Students of the Institute.

For the national best paper prize and the national prize for initial paper, only papers presented during the calendar year shall be considered except those for the best paper prize in the class of public relations and education. In this class all papers presented subsequent to those considered at the time of the last previous award in this field and prior to the end of the last calendar year will receive consideration. For the national prize for Branch papers only papers presented during the preceding academic (college) year, July 1 to June 30, inclusive, shall be considered.

Papers Must Be Submitted

All papers approved by the technical program committee which were presented at the national conventions or District meetings will be considered for the best paper prizes and initial paper prize without being formally offered for competition. All other papers which were presented at Section, Branch, or Student meetings must be submitted in triplicate with written communications to the national secretary on or before February 15 of the following year, stating when and where the papers were presented. This may be done by authors, by officers of the Institute, or by the executive committees of Sections or geographical Districts.

Basis of Grading Papers

The valuations which shall govern the grading of papers for purposes of making awards shall be as follows:

Analysis of Subject....................10 per cent

The paper shall present a clear outline of the situation out of which arises the need for the preparation of a paper on the particular subject, explaining the point of view assumed in the presentation.

Logical Presentation....................10 per cent

The presentation should include an analysis of the difficulties encountered, the methods of attack, and the solution of the problem.

Originality....................10 per cent

Credit should be given to the paper which brings to its subject matter a fresh point of view, a healthy openmindedness, or a discarding of some outworn traditions.

Unity....................10 per cent

While brevity and conciseness are important they should not be attained at the sacrifice of unity and completeness of presentation.

Value in Its Field....................30 per cent

The value of the paper as a contribution to the literature in its own field should receive particular consideration.

Value to Electrical Engineering........30 per cent

The paper should be considered from the standpoint of the quality of its contribution to the advancement of electrical engineering and its value to civilization.

Publication

Papers awarded prizes shall be published in full or in abstract, in Electrical Engineering, in the Transactions, or in pamphlet form.

District Prizes

Conditions of Awards

1. The District prize for best paper may be awarded for the best paper presented at a national, District, or Section meeting, provided the author, or at least one of coauthors, is a member of the Institute.

2. The District prize for initial paper may be awarded for the most worthy paper presented at a national, District, Section, or Branch meeting, provided the author or authors have never previously presented a paper before a national, District, Section, or Branch meeting of the Institute, and the author, or at least one of coauthors, is a member of the Institute or is a graduate student enrolled as a Student of the Institute.

3. The District prize for Branch paper may be awarded for the best paper based upon undergraduate work presented at a Branch or other Student meeting of the Institute, provided the author or authors are Enrolled Students of the Institute.

4. The District prize for graduate paper may be awarded for the best paper based upon graduate work and presented at a national, District, Section, or Branch meeting of the Institute. At the time of presentation, the author must be a graduate student and either a member or an Enrolled Student of the Institute. In the case of coauthors, the graduate requirement applies to all and the membership requirement applies to at least one of the coauthors.

Each District prize may be awarded only to an author who, or to coauthors of whom at least one, is located within the District, and for a paper presented at a meeting held within, or under the auspices of the District.

Papers Must Be Submitted

Only papers presented during the calendar year shall be considered for the prize for best paper and for initial paper. Only papers presented during the preceding academic (college) year, July 1 to June 30, inclusive, shall be considered for the prize for Branch paper and for graduate student paper. They must be submitted in duplicate by authors, or by officers of the Section, Branch, or District concerned to the District secretary on or before the following dates: best paper and initial paper, February 15; Branch paper and graduate student paper, July 15.

Committees on Awards

All the District prizes for a given calendar year shall be awarded prior to May 1 of the succeeding year by the District executive committee or by a committee appointed by the District executive committee and authorized to make such awards.

Basis of Grading Papers

The valuations which shall govern the grading of papers for purposes of making awards shall be the same as those for the national prizes but the papers will not be graded by the technical committees.

Four New Groups Join ASA. Sixty national organizations are now affiliated with the American Standards Association according to an announcement of Dana D. Barnum, president. The 4 new groups affiliated since January 1, 1937, are Automobile Manufacturers Association, Brick Manufacturers Association of America, American Society of Heating and Ventilating Engineers, and Structural Clay Products, Inc.

In Memoriam

E. B. MEYER

ON THE thirtieth day of January 1937, the Institute suffered a serious loss in the death of Edward Barnard Meyer, who had, only 6 months previously, completed his term as its forty-eighth president, and who had long been one of its most loyal and active members.

Doctor Meyer was graduated from the Newark Technical School in 1901 and from Pratt Institute in 1903. He was immediately employed by the Public Service Electric and Gas Company of New Jersey as an engineering assistant, and remained with it and its subsidiaries until 1922, rising steadily to higher positions, and being assistant chief engineer during the last 3 years. In 1922, he was appointed chief engineer of the Public Service Production Company, which was formed at that time, and, in 1929, was promoted to vice-president. Upon the merger of that company, in 1930, with the United Engineers and Constructors, Inc., he was made vice-president of the latter and executive and engineering head of its Newark office. In 1935, he returned to the Public Service Electric and Gas Company as chief engineer of the electric engineering department.

Doctor Meyer joined the Institute in 1905, and was transferred to the grade of Member in 1913 and to the grade of Fellow in 1927. He was a director 1927–31, a vice-president 1932–34, and president 1935–36. He served as chairman of many of the Institute's most important committees, as a member of others, and as an Institute representative upon numerous joint organizations. He was chairman of the New York Section 1926–27.

The Newark College of Engineering awarded him the honorary degree of doctor of engineering in 1936.

Doctor Meyer's ability as an engineer, his constant adherence to the highest ideals, his patient and persistent efforts to encourage co-operation, and the breadth and thoroughness of his consideration of all matters connected with his duties gave him an outstanding position of leadership in his chosen profession.

RESOLVED: That the executive committee of the American Institute of Electrical Engineers hereby expresses, upon behalf of the membership, its deepest regret at the death of Doctor Meyer, and its most sincere appreciation of his unusually large number of important contributions to the conduct and development of Institute activities, and be it further

RESOLVED: That these resolutions be entered in the minutes and transmitted to his family. —AIEE Executive Committee
March 25, 1937

Electronics Program. A special lecture and conference program in electronics will be held in Ann Arbor, Mich., as a part of the 1937 summer session of the University of Michigan, with the co-operation of members of the technical staffs of the General Electric Company, Westinghouse Electric and Manufacturing Company, Radio Corporation of America, and Bell Telephone Laboratories, Inc. The primary objective will be to provide an opportunity for teachers and prospective teachers of electronics, engineers and physicists engaged in electronic development work in industry, and graduate students interested in electronics to broaden and unify their grasp of fundamental electronic principles. Lectures will be given by Doctors Saul Dushman (A'13) and Lewi Tonks of General Electric, Doctors H. E. Mendenhall and F. B. Llewellyn of Bell Telephone Laboratories, Doctors Joseph Slepian (A'17, F'27) and R. C. Mason (A'26) of Westinghouse, Doctor V. K. Zworykin (M'22) and B. J. Thompson of RCA, and Professors L. B Loeb of the University of California and W. G. Dow (A'19, M'32) of the University of Michigan. A special bulletin describing the details of the program will be mailed to anyone interested upon request to Professor W. G. Dow, electrical engineering department, University of Michigan, Ann Arbor.

Medal for Papers on Welding. The board of directors of The American Welding Society has accepted a gold medal to be known as the Lincoln Gold Medal, to be presented to the author of the best paper on any phase of welding published in the *Journal* of The American Welding Society during the year October 1936 to October 1937. The medal was offered by J. F. Lincoln (A'08, M'20) president of the Lincoln Electric Company, Cleveland, Ohio. Papers to be considered must be received by the editor of the *Journal* before September 15, 1937.

To Institute Members Planning Trips Abroad

Members of the Institute who contemplate visiting foreign countries are reminded that since 1912 the Institute has had reciprocal arrangements with a number of foreign engineering societies for the exchange of visiting member privileges, which entitle members of the Institute while abroad to membership privileges in these societies for a period of 3 months and members of foreign societies visiting the United States to the privileges of Institute membership for a like period of time, upon presentation of proper credentials. A form of certificate which serves as credentials from the Institute to the foreign societies for the use of Institute members desiring to avail themselves of these exchange privileges may be obtained upon application to Institute headquarters, New York. The members should specify which country or countries they expect to visit, so that the proper number of certificates may be provided, one certificate being addressed to only one society.

The societies with which these reciprocal arrangements have been established and are still in effect are: Institution of Electrical Engineers (Great Britain), Société Française des Electriciens (France), Association Suisse des Electriciens (Switzerland), Associazione Elettrotecnica Italiana (Italy) Koninklijk Instituut van Ingeniurs (Holland), Verband Deutscher Elektrotechniker E. V. (Germany), Norsk Elektroteknisk Forening (Norway), Svenska Teknologforeningen(Sweden), Stowarzyszenie Elektrykow Polskich (Poland), Elektrotechnicky Svaz Ceskoslovensky (Czechoslovakia), The Institition of Engineers, Australia (Australia), Denki Gakkwai (Japan), and South African Institute of Electrical Engineers (South Africa).

Middle Eastern District Executive Committee Meets

A meeting of the executive committee of the Institute's Middle Eastern District was held in Pittsburgh, Pa., October 27, 1936. Circumstances have prevented reporting this meeting in an earlier issue. The meeting was attended by the following:

W. H. Harrison, vice-president, AIEE
H. A. Dambly, secretary, Middle Eastern District
H. H. Schroeder, chairman, Akron Section
H. L. Brouse, secretary, Akron Section,
A. O. Austin, Akron Section
J. H. Lampe, secretary, Baltimore Section
O. C. Schlemmer, secretary, Cincinnati Section
W. E. Wickenden, chairman, Cleveland Section
R. E. Kimberly, chairman, Columbus Section
W. D. Bearce, secretary, Erie Section
G. E. Northup, chairman, Lehigh Valley Section
O. C. Traver, chairman, Philadelphia Section
Paul Frederick, secretary, Pittsburgh Section
R. L. Dunlap, director, Pittsburgh Section
T. H. Frankenberry, Sharon Section
W. A. VanWie, Toledo Section
G. G. Coleman, Washington Section
E. O. Lange, chairman, District committee on student activities, Drexel Institute, Philadelphia

Vice-President Harrison, who presided, first discussed briefly the objectives and status of the efforts of the Institute's membership committee. A general discussion of membership activities of the Sections throughout the District followed. At the conclusion of this discussion, the report of the District prize paper committee was presented; appointment of a prize paper committee for 1936–37 was deferred.

Student conferences and conventions was the next subject discussed. The various delegates outlined briefly what is being done by their respective Sections and Branches. Vice-President Harrison urged the Sections to do all possible to assist and stimulate interest in technical schools. He called attention to the probable shortage of technically trained men in the years ahead. There was also an exchange of ideas pertaining to Section programs and activities.

To serve as the District co-ordinating committee for the year ending July 31, 1937, the following were selected: O. C. Schlemmer, W. C. Kalb (Cleveland Section), E. E. Kimberly, Paul Frederick, and E. O. Lange. The vice-president and District secretary are *ex-officio* members of this committee.

Vice-President Harrison reported that the proposed Akron (Ohio) District meeting had been approved by the Institute's board of directors on May 25, 1936. Although no definite date for the meeting was selected, early October was suggested. A. O. Austin and H. L. Brouse were designated as representatives of the Akron Section to serve on the committee for this meeting. These 2 members together with the District coordinating committee constitute the complete committee for this meeting.

A proposal to request that the Institute's 1938 summer convention be held at Pennsylvania State College was discussed in detail. Although the college is not within Institute Section territory, delegates of neighboring Sections indicated their willingness to assist. After lengthy discussion it was voted unanimously that the executive committee of the Middle Eastern District recommend that consideration be given to Pennsylvania State College for a summer convention or District meeting in 1938. (After considering this and other invitations for the 1938 summer convention the Institute's board of directors voted at its meeting of January 25, 1937, to hold the 1938 summer convention at Washington, D. C.)

French Congress on Lighting. A congress on lighting is being arranged by a French committee to be held from June 24, 1937, to a date to be set early in July during the international exposition. American lighting men have been invited to attend and to participate in discussions on lighting matters. According to Preston S. Millar, president of the United States National Committee of the International Commission on Illumination, "This congress is not to be confused with the next meeting of the ICI scheduled for next year in Holland. The French lighting congress is to be held in connection with the international exposition. The United States National Committee of the ICI, however, is lending its support and will be glad to serve as a 'clearing house' for American lighting men desiring to present papers at the forthcoming congress on lighting in Paris." Inquiries relating to the subject should be addressed to Mr. Millar, in care of Electrical Testing Laboratories, 80th Street and East End Avenue, New York, N. Y.

Springfield Section Offers Prizes for New Ideas

In an effort to develop "ways and means to advance and improve the Springfield Section of the AIEE," that Section announced at its March 12 meeting that for the best papers on that subject submitted within the ensuing 6 months, cash prizes of $25 for the best and $10 for the next best paper would be awarded at the Section's October or November meeting. All members of the Springfield Section (national, local, and student) except present Section officers, present chairmen and vice-chairmen of Section standing committees, and members of the Section's prize paper contest committee, are eligible to enter the contest.

Papers submitted are specified to be between 500 and 2,500 words in length, and subject to grading on the following basis:

Clarity of Presentation. The paper shall give a clear presentation of the merits of proposed changes and/or any defects in present practices. . 20 per cent

Originality. The paper should include new ideas for the management and activities of the Section, that will make it more interesting and of greater benefit to the largest number of members. It should bring to its subject matter a fresh point of view, a healthy open-mindedness, and/or a discarding of any outworn traditions. . . . . 30 per cent

Value to the Section. The improvements and benefits, estimated to result from adopting the ideas presented in the paper will receive particular consideration. . . . . 50 per cent

Great Lakes District Executive Committee Meets

The annual meeting of the executive committee of the Institute's Great Lakes District was held at Chicago, Ill., on November 16, 1936. Circumstances have prevented reporting this meeting in an earlier issue. The following members of the committee were present:

C. F. Harding, vice-president, AIEE
A. G. Dewars, secretary, Great Lakes District
F. L. Stanley, chairman, Central Indiana Section
Burke Smith, chairman, Chicago Section
J. A. Fitts, secretary, Chicago Section
S. S. Attwood, chairman, Detroit-Ann Arbor Section
D. H. Hanson, chairman, Fort Wayne Section
C. S. Allen, secretary, Fort Wayne Section
F. H. McClain, chairman, Iowa Section
R. R. Benedict, chairman, Madison Section
W. A. Kuehlthau, secretary, Madison Section
J. A. Potts, chairman, Milwaukee Section
J. H. Kuhlmann, chairman, Minnesota Section
C. H. Nelson, secretary, Minnesota Section
H. J. Reich, chairman, Urbana Section
K. A. Auty, treasurer, District executive committee

K. L. Hansen of Milwaukee, chairman of the 1937 summer convention committee, was present by invitation.

Vice-President Harding presided. Following the presentation of the treasurer's report, Mr. Auty was re-elected treasurer for the ensuing year. The following were chosen to serve on the District co-ordinating committee for the ensuing year: Burke Smith, R. R. Benedict, F. L. Stanley, and J. A. Potts; these, together with Vice-President Harding and District Secretary Dewars, who serve as *ex-officio* members, constitute the complete committee.

Concerning the Institute's 1937 summer convention to be held in Milwaukee, Wis., June 21–25, K. L. Hansen reported that the various committees had been active and were already well along on their way toward completion of their plans. He called attention to the proposal to include on the program a paper, or papers, on economic or social subjects and asked the opinion of the members of the District executive committee on this matter. Vice-President Harding had mentioned at the opening of the meeting that the Institute's board of directors had considered the general question of broadening Institute activities to include discussions on social and economic subjects, at its meeting of October 20, 1936. After considerable discussion, a committee was appointed to prepare a resolution expressing the attitude of the District executive committee on the general subject of including papers of this type on convention programs. At the close of the meeting, this committee, which consisted of F. L. Stanley, D. H. Hanson, and Burke Smith, offered the following resolution:

> "Resolved, That the executive committee of the Great Lakes District hereby goes on record as endorsing the action taken by the board of directors of the American Institute of Electrical Engineers at its meeting on October 20, 1936, in which it favored broadening of the scope of papers for national presentation and publication, to include topics of economic and sociological interest to the profession."

The resolution was adopted and the secretary was instructed to forward a copy to the Institute's board of directors.

Reports were presented by the various Section delegates, in which the activities of the respective Sections during the preceding year were described, and plans for the coming year outlined. Practically all of the Sections represented reported an increase in membership during the preceding year.

Medals Awarded for Public Service

Two awards of the American Institute of the City of New York for 1937—a gold medal to the Bell Telephone Laboratories, New York, N. Y., and a fellowship to Watson Davis, director of Science Service, Washington D. C.—were announced December 28, 1936, by Dr. Gerald Wendt, director of the organization, and presented February 4, 1937.

The gold medal, given annually by the organization in recognition of outstanding accomplishment in research, was awarded to the Bell Telephone Laboratories "for researches in electrical science which, applied to communication, have promoted understanding, security, and commerce among peoples by transmitting human thought instantly throughout the world."

One of the pioneer industrial organizations for scientific research, Dr. Wendt said, the Bell Telephone Laboratories developed and perfected many of the valuable means of modern communication. Its outstanding achievements have been in the development of the instrumentalities on which are based a nation-wide system of communication. The award was received in the name of the more than 4,000 men and women of the Laboratories by its president, Dr. F. B. Jewett (A'03, F'12, past-president).

The fellowship, conferred for "outstanding service in the interpretation of science to laymen," was awarded to Watson Davis "for interpreting to the people of the Nation the rapid progress of science upon which modern civilization depends, and for the organized dissemination of research findings as news."

Mr. Davis is director of Science Service, a pioneer organization in the interpretation and dissemination of the news of science. He is well known as author and editor of books on scientific subjects including "The Story of Copper", "Science Today," and "The Advance of Science." His articles, appearing regularly in newspapers, magazines, and technical journals, bring science to the people in the language of the layman.

The council on awards of the American Institute of the City of New York consists of: M. L. Crossley (chairman) Calco Chemical Co.; Oscar Riddle, Carnegie Institution, Station for Experimental Evolution; W. D. Coolidge (A'10, F'24) General Electric Co.; W. H. Carrier, Carrier Engineering Corp.; Oliver Kamm, Parke Davis & Co.; Ward F. Davison (A'14, F'26) Brooklyn Edison Co.; L. O. Kunkel, Rockefeller Institute for Medical Research; Clinton J. Davisson, Bell Telephone Laboratories; and Harden F. Taylor, Atlantic Coast Fisheries.

The American Institute of the City of New York was incorporated in 1828 for the purpose of "encouraging and promoting domestic industry in this State and in the United States." Its membership includes leading scientists and others interested in promoting this aim. Its work among school children, including its "science congress," "Christmas lectures," and "children's science fair," is notable.

Production of Electricity in 1936 Breaks All Records

PRELIMINARY figures on the total production of electricity for public use in the United States in 1936, as given by the Federal Power Commission, indicate a total output of 113,473,000,000 kilowatt-hours, which is an increase of 14 per cent over that for 1935, the year of the previous maximum.

The production of electricity by the use of water power was about 40,893,000,000 kilowatt-hours, or 2 per cent more than in 1935, and amounted to 36 per cent of the total, whereas the average for the 16-year period, 1920 to 1935, was 36.9 per cent of the total. The percentage for 1936 indicates that despite the abnormal conditions experienced in the drought-stricken states the production of electricity by the use of water power is maintaining its relative position with respect to other sources of power.

The preliminary data indicate that the fuel rate for 1936 was about 1.45 pounds per kilowatt-hour as compared with 1.46 pounds per kilowatt-hour in 1935. Following the former procedure of the U.S. Geological Survey, the fuel rate was calculated by converting the oil and gas used in the production of electricity into equivalent tons of coal and dividing the total coal used in producing electricity and coal equivalent of the gas and oil used by the corresponding output. This method does not allow for the variation in Btu content of the gas and oil as fired, and includes the output of both steam and internal combustion engines, and is therefore only approximate.

An analysis of all steam plants using coal exclusively for fuel indicates that the coal rate is 1.49 pounds per kilowatt-hour. Since these data include coal used in plants held in reserve and operated intermittently, it is not representative of good practice. Some of the more efficient plants are producing a kilowatt-hour with approximately 0.8 pound of coal at the present time.

The accompanying tables show for the United States and its divisions the annual production of electricity for public use by use of water power and by the use of fuels for the years of 1935 and 1936 and the percentage change from 1935 to 1936 in the production of electricity and in the use of different fuels in generating electricity. The information is preliminary and is based on the figures of production of electricity in the monthly reports during 1936. The output of central stations, both publicly and privately owned, electric railway plants, plants operated by steam railroads generating electricity for traction, and U.S. Bureau of Reclamation plants and that part of the output of manufacturing plants which is sold are included in these data. Accurate data are received each month representing approximately 98 per cent of the total output shown; the remaining 2 per cent of the output is estimated so that the data represent 100 per cent of the generation.

A final report, which will give totals for each state for 1936 and include final revisions of previously published data, will be published in April 1937; copies may be obtained by application to the Federal Power Commission, Washington, D. C.

Annual Production of Electricity for Public Use in the United States, 1935 and 1936

	Production of Electricity—Millions of Kilowatt-Hours								
	Total			By Use of Water Power			By Use of Fuel		
	1935	1936	Change—Per Cent	1935	1936	Change—Per Cent	1935	1936	Change—Per Cent
United States	99,398	113,473	+14	39,968	40,893	+ 2	59,430	72,580	+22
New England	6,914	7,496	+ 8	2,950	2,852	− 3	3,964	4,644	+17
Middle Atlantic	25,905	29,281	+13	7,836	7,348	− 6	18,069	21,933	+21
East North Central	22,833	26,384	+16	2,686	2,310	−14	20,147	24,074	+19
West North Central	6,588	7,026	+ 7	2,148	1,497	−30	4,440	5,529	+25
South Atlantic	11,430	13,746	+20	6,495	7,137	+10	4,935	6,609	+34
East South Central	4,206	4,985	+19	3,458	3,865	+12	748	1,120	+50
West South Central	4,879	5,634	+15	286	168	−41	4,593	5,466	+19
Mountain	3,518	4,309	+22	2,681	3,256	+21	837	1,053	+26
Pacific	13,126	14,612	+11	11,428	12,460	+ 9	1,698	2,152	+27

Annual Consumption of Fuels in Generating Electricity for Public Use, 1935 and 1936

	Coal—Thousands of Net Tons			Oil—Thousands of Barrels			Gas—Millions of Cubic Feet		
	1935	1936	Change—Per Cent	1935	1936	Change—Per Cent	1935	1936	Change—Per Cent
United States	34,807	41,973	+21	11,393	14,110	+24	125,239	155,525	+ 24
New England	2,025	2,380	+18	2,622	3,198	+22	0	0	0
Middle Atlantic	11,133	13,129	+18	3,356	4,868	+45	1,602	4,773	+198
East North Central	13,627	16,274	+19	145	183	+26	9,476	13,359	+ 41
West North Central	3,041	3,627	+19	785	927	+18	25,002	30,727	+ 23
South Atlantic	3,033	4,076	+34	2,331	2,548	+ 9	1,432	2,682	+ 87
East South Central	599	880	+47	98	112	+14	4,488	5,465	+ 22
West South Central	764	889	+16	768	903	+18	60,895	72,594	+ 19
Mountain	585	718	+23	294	370	+26	4,304	5,085	+ 18
Pacific	0	0	0	994	1,001	+ 1	18,041	20,840	+ 16

John Scott Awards for 1937 Presented

Doctors W. D. Coolidge (A'10, F'34) and Irving Langmuir, director and associate director respectively of the research laboratory of the General Electric Company in Schenectady, N. Y., and Doctor Evarts A. Graham of the school of medicine of Washington University in St. Louis, Mo., were recipients of the John Scott awards for 1937 granted by the City Trusts of the City of Philadelphia and presented at a recent dinner of the American Philosophical Society. With each award went a certificate, a copper medal, and $1,000 in cash. Doctor Coolidge accepted the award for Doctor Langmuir in the latter's absence.

The award to Doctor Coolidge was based on his application of a new principle in X-ray tubes; to Doctor Langmuir for his physical and chemical discoveries resulting in improved gas-filled incandescent lamps; and to Doctor Graham for his application of the X ray to the study and diagnosis of gall-bladder conditions.

In making the presentations, Ernest I. Trigg, chairman of the Board of City Trusts, explained that history had made but scant recordings of John Scott, the donor of the fund, and his reason for bequeathing to the City of Philadelphia in 1816 the sum of $4,000, the income from which was to be "laid out in premiums to be distributed among ingenious men and women who make useful inventions."

It was originally stipulated that no award was to carry a cash premium of more than $20 and the medal was to be inscribed "To the most deserving."

History reveals that John Scott was a chemist in Edinburgh, Scotland, but just why he chose Philadelphia for his grant is a mystery. It is thought his attention had been drawn to the city either through the American Philosophical Society or his admiration of Benjamin Franklin whom he may have met when Franklin visited Scotland in 1769. When the fund was taken over by the Board of City Trusts, the principal had grown to $21,000 and in 1917, or 100 years after the original grant, it amounted to $100,000. At this time the board appealed to the courts and received permission to increase the amount of the awards to a maximum value of $2,000, but none has been for any amount greater than $1,000.

In the period between 1920 and 1937 inclusive, 73 awards were made to outstanding scientists and inventors in all parts of the world, including Japan, Holland, England, France, Italy, and South America. Recipients have included Madam Curie, Reginald A. Fessenden, Orville Wright, Lee De Forest (A'04, F'18), Thomas A. Edison (A'84, M'84, HM'29, past vice-president, deceased '33), Guglielmo Marconi (HM'17), Samuel M. Vauclain, W. L. R. Emmet (A'93, M'94, HM'33, past vice-president, member for life), Nikola Tesla (A'88, F'17, member for life), Charles F. Kettering (A'04, F'14), and Edward G. Budd.

$100,000 Edison Memorial Gift of W. S. Barstow

The Edison Pioneers, composed of early associates of Thomas Alva Edison, met February 11, 1937, in New York, N. Y., to observe the ninetieth anniversary of Edison's birth. At that meeting, it was announced that a 135-foot concrete tower surmounted by a huge electric-light bulb would be erected in Edison's memory during the summer of 1937 on the site of his early laboratory at Menlo Park, N. J. The tower, which will cost more than $100,000, will be the gift of W. S. Barstow (A'94, F'12) retiring president of the Edison Pioneers. (Mr. Barstow served the AIEE as a manager in 1900–03, and as a vice-president in 1903–05.) Mr. Barstow specified that the gift was to the Thomas Alva Edison Foundation in the name of the Edison Pioneers.

The Thomas Alva Edison Foundation was conceived jointly by the Edison Pioneers and the AIEE, with the approval of the Edison family, and was incorporated in 1935. Its purpose is to carry out plans to perpetuate recognition of the world's progress emanating from the inventor's efforts. The construction of this memorial tower constitutes one phase of the Foundation's program.

It is planned to build a concrete tower around the skeleton steel tower which was erected in 1929, 2 years before Edison's death. The light which will be at the top is that which is now at the top of the steel structure. It is a bulb-like light composed of more than 900 incandescent lamps, and will be enclosed in prismatic glass. Edison turned it on from Dearborn, Mich., on October 21, 1929, during the national celebration of the fiftieth anniversary of his invention of the incandescent electric light. It has burned every night since and will not be extinguished during the construction of the new tower.

Electrical Vocabulary Prepared by IEC

The International Electrotechnical Commission plans publication of the first edition of its "International Vocabulary" in 1937. This work, undertaken soon after the St. Louis Electrical Congress in 1904, contains some 2,000 scientific and industrial terms used in the various branches of electrotechnics. It is the result of many years of continuous effort by a committee of experts including delegates from Austria, France, Germany, Great Britain, Italy, the Netherlands, Poland, Spain, and the United States.

Definitions appear in English and French, the 2 official languages of the IEC, and a translation of terms is given in German, Italian, Spanish, and Esperanto. While the committee developing this international vocabulary appreciates that it does not constitute a complete unification of electrotechnical nomenclature, through periodic review and revision based on the constructive criticism of electrical authorities throughout the world it should become increasingly valuable to engineers.

The edition will be limited, and copies at about $2.50 each may be reserved by writing to the United States National Committee of the International Electrotechnical Commission, 29 West 39th Street, New York, N. Y.

Electrical Treatment of Air. A new technical subcommittee on the treatment of air with electricity, formed under the committee on research of the American Society of Heating and Ventilating Engineers, recently held its first meeting to plan a research program directed toward discovering, if possible, and duplicating in indoor conditioned air, certain intangible qualities that seem to give outdoor air a particular zest and life. Discussion at the meeting included the problem of ozonization, ionization, and treatment of air with ultraviolet rays, which has shown possibilities in the killing of air-borne disease germs, and the subject of electrical filtering of air by precipitation processes. Members of the subcommittee include L. W. Chubb (A'09, F'21, past director) director of research laboratories of Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and Vannevar Bush (A'15, F'24) vice-president and dean of engineering at Massachusetts Institute of Technology, Cambridge.

American Engineering Council

Council Acts on Patent Situation

In all the flurry of patent legislation in recent years, Council's patents committee has kept closely in touch with the situation and has acted in the interest of engineers and the public where opportunity was found to improve patent-court conditions and patent-office procedure. Of most importance are actions taken on the proposed court of patent appeals and legislation affecting pooling and cross-licensing.

The committee has recommended that Council support legislation for a single court of patent appeals, and the AEC assembly has approved the recommendation and has taken the position that it will look with favor upon the idea of having the judges named to such court selected by the President and confirmed by the Senate only after careful review of their special and technical competence with the advice of engineering and scientific societies as well as the advice of the patent bar and the legal profession.

Scientific advisers to the courts have been recommended by a number of agencies, but not all with the same purpose. Most often quoted is the suggestion of a special patents committee of the Science Advisory Board. That committee recommended that scientific advisers be made available to aid *trial* court justices. In this conclusion, the committee agrees with the recommendations of the special patents committee of the Science Advisory Board. The patents committee looks with some favor on such an idea if a suitable method of selecting advisers free from preconceived opinions were fixed and if a sufficiently diversified list of skilled scientific and engineering talent were made available. However, the committee has doubted the wisdom of having such scientific advisers named permanently as a part of a new single court of patent appeals. It feels that the idea of naming 3 such advisers who would serve for all classes of cases would not afford such highly skilled aid in all divisions of science and technology as courts really require.

The committee believes that the public interest has been much more served than harmed by patent pools and by cross-licensing. Such evils as may have been experienced would not have been corrected by any of the proposed forms of legislation. The committee believes that administration of present laws, including proper and reasonable application of antitrust legislation, would suffice to correct those types of evils of pooling that have been disclosed or charged as bad practice.

Council also has approved the patents committee's recommendation to oppose all the various types of proposals which would restrict the freedom of owners of patents to use them constructively under present laws. It regards such offenses as are now charged against the patent system as the result of defects in administration of present laws and not as evidence of the need of more legislation.

The committee believes that every effort should be made by industry as well as by the engineering profession to increase the presumption of validity of patents as issued. It feels that engineers generally should assist patent examiners whenever possible to keep abreast of the arts with respect to which they are examining patent applications. The committee has not found any legislation, proposed to date, sufficiently constructive to feel that it deserves support of AEC. It does, however, hope that some means may be developed for increasing the standards of competence and experience of the staff of examiners in the Patent Office.

The staff is following legislation for the court of patent appeals in *S.*475 introduced by Senator McAdoo of California, and the patents committee is giving further consideration to such matters as technical advisers to the courts, patent pooling and cross-licensing, compulsory working and licensing, automatic validation of patents 5 years after issue, and taxation during nonuse.

AEC Unites Opinion On Rural Electrification

In its unbiased approach to the subject, Council's rural electrification committee seems to have made a real contribution toward a better understanding of the practical uses of electricity on the farm and toward a meeting of private and public minds on sound practices in rural electrification. The report of this committee's Report for 1936 was referred to by Morris L. Cooke, ex-administrator of REA, in a letter to the editor of the New York *Times* entitled "Rural Electrification" which was published in the February 1, 1937, issue of the *Times*. Mr. Cooke is also reported to have referred publicly to the report as representing an excellent approach to rural electrification.

Utilities and private industry also have sought copies of this report. All criticism received has been constructive and directed toward improving the recommendations for increasing the use of electricity on the farm and making the use pay dividends to the farmer in health, time-saving, and economy. Other suggestions concern ways and means to make rural distribution systems pay their own way, and the construction of rural lines of the lowest cost consistent with quality and service.

The AEC rural electrification committee made 5 recommendations with the ultimate well-being of citizens in rural life as the final objective: (1) every farmer who can use electricity economically should be supplied with it; (2) service should be supplied in the most efficient and dependable manner and at the lowest cost consistent with quality and service; (3) each farm operator should be informed as rapidly as possible regarding the electric-power and equipment needs of his own individual farm; (4) each farmer should be informed as rapidly as possible regarding the best ways of using this power and equipment so that the greatest economy may be effected; and (5) every effort should be made to develop new equipment and processes whereby electric power can be used to bring the farmer closer to his market, whether he is selling food products or the raw materials of industry.

In conclusion, the report advances the opinion that such a program of rural electrification will require the utmost co-operation between all branches of the agricultural and engineering professions, and all agencies, public and private, that are involved in this development. The problem is a tremendous one, but its solution will go so far in helping to solve the economic problems of American agriculture, and indirectly the economic problems of the nation, that it is worth the best efforts of all who have anything to contribute to it.

Rural Electrification Administration Notes

Rural Electrification Administration news is the resignation of Administrator Morris L. Cooke. Mr. Cooke is reported to have resigned voluntarily to seek a rest from the burden of responsibility that the President drafted him to carry from the creation of the REA. An interesting rumor in connection with Mr. Cooke's resignation is the unofficial report that his friendly consideration of the interests of privately owned utilities added to the burden of his responsibility and engendered trying misunderstandings among his liberal colleagues.

John M. Carmody, an editor and industrial engineer, formerly a member of the National Labor Relations Board, chief engineer of CWA and FERA, with much experience in the railroad, steel, and coal industries and in private practice, succeeded Mr. Cooke. He is being assisted by Colonel George D. Babcock of North Carolina who was associated with Mr. Carmody in the other emergency agencies.

At the conclusion of Mr. Cooke's administration, REA had lent or ear-marked a total of more than $50,000,000 for 257 rural electric projects to serve 165,000 rural customers in 40 states and Alaska. These figures do not include funds involved in contracts providing that the Electric Home and Farm Authority co-operate with both public and private utilities in financing the sale of electric appliances for use by consumers located on public and private utility power lines.

Engineering Foundation

Doctor A. D. Flinn, Director of Foundation, Dead

Doctor Alfred Douglas Flinn, director of The Engineering Foundation, died March 14, 1937, at Scarsdale, N. Y., after a prolonged illness. He was born in New Berlin, Pa., August 4, 1869. He was graduated in 1893 from Worcester (Mass.) Polytechnic Institute, with the degree of bachelor of science in civil engineering, following which he took postgraduate work at the Massachusetts Institute of Technology, Cambridge. The University of Louvain, at its 500th anniversary celebration in 1927, conferred on him the degree of doctor of applied science, *honoris causa*. He received the honorary degree of doctor of engineering from Worcester Polytechnic Institute in 1932.

From 1894 to 1895, Doctor Flinn was employed successively by: Rice and Evans, civil engineers, of Boston, Mass.; Associated Factory Mutual Fire Insurance Companies, Boston; Waterworks Division of the Boston City Engineer's Office. From 1895 to 1902, he was engineer for the Massachusetts Metropolitan Waterworks, becoming principal assistant engineer. He served as managing editor of *The Engineering Record* (later combined with *The Engineering News*) 1902–04, following which he became general inspector for the Croton Aqueduct Commissioners, being in charge of their New York engineering office. In August 1905, he became associated with the Board of Water Supply of the City of New York, which he served until January 1918. He was successively division engineer, department engineer of headquarters, deputy chief engineer, and, on several occasions, acting chief engineer.

In January 1918, Doctor Flinn was named secretary of the United Engineering Society, which was succeeded by Engineering Foundation and United Engineering Trustees, joint agencies of the 4 Founder societies. He continued as secretary of United Engineering Trustees until June 23, 1934, and of The Engineering Foundation until his death. He became director of Foundation in 1922.

As secretary, or executive officer, of United Engineering Trustees, he supervised the Engineering Societies Building at 29 West 39th Street, executed and recorded the actions of the board of trustees, including administration of trusts and other funds, and rendered secretarial services to standing and special committees. After his resignation in 1934 he continued some special services until the end of that year, when his engagement with the Trustees ended.

In co-operation with National Research Council, Doctor Flinn aided in developing and financing the Fatigue of Metals Research, the Arch Dam Investigation, the Alloys of Iron Research, and the Education Research Committee, including the pamphlet, "Engineering: A Career—A Culture." He also assisted smaller researches and the special research committees of the Founder societies and organizations co-operating with them.

He was instrumental, in conjunction with the National Research Council, in establishing the Personnel Research Federation, the Highway Research Board, and the American Bureau of Welding; and in conducting the Marine Piling Investigation, and the compilation of the Directory of Industrial Research Laboratories in the United States.

Doctor Flinn was assistant secretary of the John Fritz Medal Fund Corporation from 1920 to 1935. In February 1928, he was elected secretary and treasurer of the Daniel Guggenheim Medal Fund; he resigned as treasurer in May 1935, and relinquished his duties as secretary in May 1936.

He was a Fellow of the American Association for the Advancement of Science, and a member of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Mathematical Society, American Iron and Steel Institute, Sigma Xi, Sigma Alpha Epsilon, the Century Association, and the Engineers' Club. He was a past-president of the Municipal Engineers of the city of New York and holder of its gold medal for the best paper of the year. He was honorary foreign member of the section of engineering sciences of the Masaryk Academy of Prague, Austria, and a Knight of the Order of the White Lion, Republic of Czechoslovakia.

With R. S. Weston and C. L. Bogert, he compiled a "Waterworks Handbook," now in its third edition and extensively used in the United States and other countries. He originated and edited for 12 years the "Research Narratives" printed by the Engineering Foundation. He was also the author of many technical papers and chapters in technical books.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. Electrical Engineering will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy, to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Short-Time Spark-Over of Gaps

To the Editor:

The paper "Short-Time Spark-Over of Gaps," by J. H. Hagenguth (Electrical Engineering, volume 56, pages 67–76, January 1937) gives rise to several questions.

The curves *B* of figure 14 (page 74), showing the relations between breakdown voltage and time to breakdown of a 20-inch, rod gap for both positive and negative surges, cross in 2 places. No experimental points are shown on the curves—but if the author's estimates of from 10 to 20 per cent accuracy in determination of time to breakdown are accepted one might wonder if there is justification for showing 2 distinct curves. If the curves represent the physical picture correctly, the explanation for the negative surge breakdown time being both higher and lower than that for a positive surge, depending upon the magnitude of the overvoltage, might be that given below.

It will be noted that the minimum breakdown potential is always lower for a positive surge. The difference is small for suspension-insulator spark-over, amounts to 30 per cent in some cases for rod gaps. The fields at the 2 electrodes of the suspension insulator are probably nearly alike. However, because of the proximity of the ground plane the field at the grounded electrode of the rod gap is much less than at the ungrounded electrode. From simple sparking theory the sharper gradient at the cathode should give a lower breakdown potential.[1] Since the tests referred to in the paper are at high pressure, the theory of "electron avalanche" [2,4] must be invoked. The increase in gradient caused by the electron avalanche is in some cases only 14 per cent of the existing gradient.[4] The electron avalanche (with a lack of a positive source of electrons by illumination) might begin anywhere between the electrodes and reach its maximum value in the vicinity of the anode. Hence, for minimum breakdown potential the positive surge, with higher gradient at the ungrounded electrode due to both dissymmetry of the field and the electron-avalanche field, would be expected to give a lower breakdown voltage than a negative surge with only the dissymmetry of the field to give a high gradient.

In the case of overvoltage the problem is not quite the same, for we are dealing with the time required for breakdown. The potential gradient with either surge certainly will cause breakdown; it is only a question of how long a time before breakdown. On a statistical basis it might be expected that a negative surge will give a lower time to breakdown, for the electron avalanche certainly would have a considerable magnitude in the vicinity of the cathode, thus increasing the field at this point in a time shorter than that required for motion of the avalanche to the high field of the anode and the time for propagation of the secondary process of ionization to the cathode. These deductions are borne out in the tests involving a large distance between electrodes as shown in curves *A* and *B* figure 10, page 72, for intermediate overvoltages. (Note that the ordinates are per cent over voltage.) For the third case of very great overvoltage the times of breakdown should be about the same regardless of polarity of the surge, within the limits of the experimental error given by Hagenguth, as shown in figures 10 and 14.

The choice of definition of rate of voltage rise applied to surges given on page 71 seems consistent enough from examination of figure 9 and comparing it with figure 14. This brings up the method of measuring rate of rise of voltage for a voltage variation similar to figure 7*b* with an accentuated first rise. Here rate of rise would be smaller factor compared with the effect of 2 sudden voltage impulses. In standardizing a definition, or in expressing the results of tests, some limitation should be made on the magnitudes of a disturbing initial voltage pulse.

References

1. Conduction of Electricity in Gases (a book), J. Slepian. Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., 1933, page 129.

2. Breakdown of Spark Gaps, J. Slepian. *Electrical World*, volume 91, April 14, 1928, pages 761–5.

3. Stosspannung und Durschlag bei Gasen, W. Rogowski. *Archiv fur Elektrotechnik*, volume 20, May 11, 1928, pages 99–106.

4. Mechanism of Static Spark Discharge, L. B. Loeb. *Review of Modern Physics*, volume 8, July 1936, pages 267–93.

Very truly yours,

G. H. Fett (A'32)

Assistant in Electrical Engineering,
University of Illinois, Urbana

Engineers and Government

To the Editor:

The engineering profession has, of late, been running the gamut of sharp criticism from those of the "more abundant life" diagnosticians who like to believe that we are the cold lobsters responsible for such economic nightmares as that from which the world is just awaking.

These pragmatists are convinced that we fiddled too much with logarithms and slide rules while the world burned in the fire of so-called technological unemployment, and that hereafter we should take it upon ourselves to pay as much attention to the efficiency of our economic apparatus as to the efficiency of our industrial and power-station equipment. Thus, they would have us practice not only engineering but also economics, sociology, finance, banking, and even black magic, and thereby distend ourselves into a legion of supermen, capable of designing skyscrapers and transformers for 40 hours a week and solving the problems of money and state in our off hours.

At first thought, the very audacity of the proposal is flattering, but upon reflection it becomes apparent that the critics are indulging in the old game of passing the buck on to the geese that squawk the least. Engineers undoubtedly are less well organized than the members of other major professions, such as the medical and the legal and hence the little squawking that we do at times is perfunctory and in no way comparable to the unanimity of the 10,000,000-decibel squawk that comes from the throat of the American Medical Association, for instance, whenever it is pricked with a pin.

So that, far from swelling with pride at the suggestion that we must become a body of cure-all practitioners, we should, in the interest of tolerance, earnestly struggle against the natural impulse to laugh in our critics' faces. For the underlying weakness of their case lies in the fact that they almost wholly lack acquaintance with engineering problems and, typical of the clan of critics the world over, they find it far easier to stand without and grimace, and denounce the inner workings of a thing, than to take the trouble to learn something about what they are denouncing, and perhaps offer some constructive suggestions.

What they believe, no doubt, is that history and political science can be neatly and conveniently contained in a hypodermic syringe of some form, to be injected into the arm or leg of the student engineer at will, and in zero time. Because, if they have the slightest inkling of what they talk about, they must recognize the fact that the engineering school curriculum of 4 years falls far short of supplying the student with even adequate engineering training, and that at least another 2 years would be necessary to fulfill this primary requisite. They should know, too, that anything less than 6 years special study in the social sciences is wholly inadequate, and if they can add 6 and 6, they might get 12. Now 12 years of organized study, besides tending to create academicians and school teachers, is an expensive proposition, and such a course would leave the engineering profession open to rich men only (which, in itself, might not be a bad idea!). Further, the field of inquiry of pure engineering is so intricate and broad that only the best minds available can cope with it in a reasonably intelligent manner, and any scheme that calls for a mind able to cope with it, plus the problems of 4 or 5 other professional groups that can't even handle their own, is sheer nonsense, and unworthy of even the third-rate politicians who voiced it.

This is not to say that we, as a profession, are totally disinterested in society's problems. On the contrary, it is my belief that the engineer, in general, has a keener appreciation of the issues involved than have any other professional groups, and we would be more than happy to assist the nation's statesmen in their work. But the trouble is that politicians take to sound advice in precisely the same manner that a gagging infant takes to cod liver oil. Past experience has demonstrated amply the inadvisability of administering counsel in any but infinitesimal doses, and the chances are about *n* to 1 against the lawmaker digesting even those.

Very truly yours,

RICHARD B. KAUFMAN (A'35)

54 Wendell Avenue,
Pittsfield, Mass.

Wave Forms in Frequency-Tripling Transformers

To the Editor:

In the July 1936 issue of ELECTRICAL ENGINEERING the paper "Frequency Tripling Transformers," by J. L. Cantwell, shows the characteristics of one method of frequency tripling. The purpose of this letter is to show oscillograms of the wave forms of voltages and currents in Cantwell's frequency-tripler circuit.

Three similar transformers, with rated primary and secondary voltages of 110, were connected as shown in figure 1. Since the fundamental input line-to-neutral voltage was $235/\sqrt{3}$, or 136 volts, the transformers were operated at flux densities somewhat above normal. As shown in Cantwell's paper, this increase of flux density above normal increased the amount of the third-harmonic voltage output.

With no load on the secondary the third-harmonic output voltage was 206. The wave forms of the primary line-to-neutral voltage and the primary line current for this condition are shown in the oscillogram of figure 2. The voltage wave contains a very prominent third harmonic. The current wave contains a noticeable fifth harmonic.

When a resistance load was connected to the output terminals the output voltage dropped rapidly with an increase of output current. The voltage decreased from 206 volts at no load to 103 volts for a load current of 0.78 ampere. The wave forms for this load condition are shown in the oscillogram of figure 3.

In order to make easier the comparison of wave forms for no load and for some load, the oscillogram of figure 4 was taken. This oscillogram shows the wave forms of figures 2 and 3 in the correct phase positions relative to each other, and to the same scales.

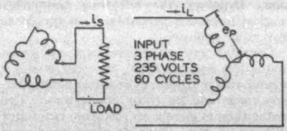


Fig. 1. Diagram of a frequency-tripling circuit

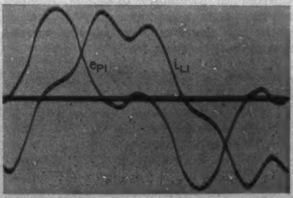


Fig. 2. Oscillogram of primary line-to-neutral voltage and line current with no load on the secondary of the frequency-tripling circuit

e_{P1}—Primary phase voltage
i_{L1}—Primary line current
I_{L1}—2.02 amperes, effective
A unit length equals 5.13 amperes and 445 volts (the base of 1/2 cycle is taken as a unit length)

Figure 4 shows that as the output current is increased the magnitude of the third-harmonic component of the voltage and the peak value of voltage are reduced. As the output current is increased the primary line current is changed somewhat in wave form, and its peak value is increased.

When a 4.73-microfarad capacitor was connected in series with the resistance load the wave forms became those shown in figure 5. In this case the voltage across the resistance load dropped only to 162 volts at a current of 1.45 amperes.

It is of interest to note that the output current i_{S2} appears to contain a component which is a third harmonic with respect to it. This component thus is a ninth harmonic with respect to the fundamental.

The oscillogram of figure 6 shows the wave forms of figures 2 and 5 in the correct relationship with respect to each other. The wave i_{L1} represents the same current in both figures 2 and 6 but the scale is not the same in each case.

Figure 6 shows that the use of a capacitor in series with the load increases the magni-

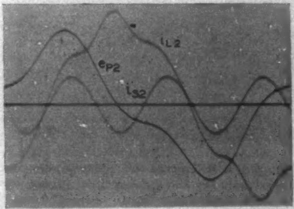


Fig. 3. Oscillogram of primary line-to-neutral voltage, primary line current, and output current, with a resistance load

e_{P2}—Primary line-to-neutral voltage
i_{L2}—Primary line current
I_{L2}—2.24 amperes, effective
i_{S2}—Output current
I_{S2}—0.78 ampere, effective
A unit length is 5.13 amperes and 445 volts

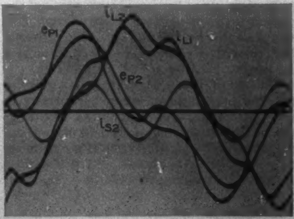


Fig. 4. Oscillogram of primary line-to-neutral voltages and primary line currents at no load and under load; output current under load conditions

e_{P1}—Primary line-to-neutral voltage at no load
e_{P2}—Primary line-to-neutral voltage under load
i_{L1}—Primary line current at no load
I_{L1}—2.02 amperes, effective
i_{L2}—Primary line current under load
I_{L2}—2.24 amperes, effective
i_{S2}—Output current
I_{S2}—0.78 ampere, effective
A unit length is 5.13 amperes and 445 volts

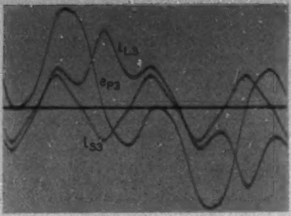


Fig. 5. Oscillogram of primary line-to-neutral voltage, primary line current, and output current, with a capacitor in series with the resistance load

e_{P3}—Primary line-to-neutral voltage
i_{L3}—Primary line current
I_{L3}—2.7 amperes, effective
i_{S3}—Output current
A unit length equals 9.1 amperes and 445 volts

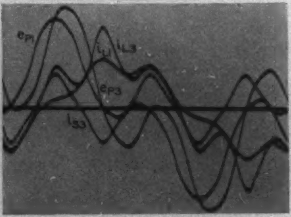


Fig. 6. Oscillogram of primary line-to-neutral voltages and primary line currents at no load and under load, output current under load conditions

e_{P1}—Primary line-to-neutral voltage at no load
e_{P3}—Primary line-to-neutral voltage under load
i_{L1}—Primary line current at no load
I_{L1}—2.02 amperes, effective
i_{L3}—Primary line current under load
I_{L3}—2.7 amperes, effective
i_{S3}—Output current
I_{S3}—1.45 amperes, effective
A unit length is 9.1 amperes and 445 volts

tude of the third-harmonic component of the primary line-to-neutral voltage and also the peak value of the voltage. The primary line current is changed in wave form and its peak value is increased appreciably.

The point made by Cantwell regarding possible overvoltages, when a capacitor is used, is an important one. At one time the writer connected a 10-microfarad capacitor across an open corner of the delta on 3 110-volt transformers. The voltage across the capacitor was found to be more than 1,110 volts.

The transformers used in obtaining the oscillograms shown in this letter were not designed to be used as frequency triplers. The exciting currents are rather large in comparison with the output current, but the general nature of the wave forms in a frequency tripler can be predicted from the oscillograms shown.

Very truly yours,
G. V. Mueller (A'29, M'35)
Assistant Professor of
Electrical Engineering, Purdue
University, Lafayette, Ind.

Qualitative Analysis of Self-Excited A-C Generator

To the Editor:

An article in the May 1935 issue of Electrical Engineering on the subject of self-excited a-c generators of the induction type gave what may be regarded as an introduction outlining the possibilities of using a squirrel-cage induction motor as a generator by connecting suitable capacitance across the terminals and driving the machine mechanically. It may be inferred from this article that the electrical losses plus the load are supplied from the mechanical input; but it is not made clear just how the conversion from mechanical to electrical energy occurs. Also, the question of what determines the output frequency is not satisfactorily answered.

It is not sufficient explanation of the operation of such a machine merely to say that the capacitance draws a leading current (resulting from residual magnetism voltage) which is magnetizing, and therefore the initial voltage increases. This does not take into account the function of the rotor conductors. The operation may be partially explained by saying that a salient-pole rotor less conductors may build up on capacitive load without d-c excitation; and that the bars in a cylindrical squirrel-cage rotor tend to carry the flux around the air gap so that it cuts the stator conductors just as the salient-pole rotor does (except for slip necessary to have this effect).

Such an explanation is helpful but does not explain matters completely.

A concept of all the phenomena involved undoubtedly may be obtained by several different approaches. One approach, which would be of most value quantitatively no doubt, would be to set up equations for all voltages and currents and fluxes, applying Kirchoff's laws for the final solution. However, the following nonmathematical approach probably is as simple as any other concept.

Consider first a squirrel-cage induction motor less squirrel cage; in other words a wound stator with a cylindrical laminated-iron rotor and no rotor conductors. The stator then is merely an iron-core reactance with an air gap. A single-phase winding is taken for simplicity.

Now if a charged capacitor is connected across the terminals, its energy is dissipated through an oscillatory discharge, damped by the stator resistance. If resistance is neglected, the frequency of the current flowing will be given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Now suppose rotor bars are introduced and the rotor is driven at a speed

$$RPM = \frac{2 \times 60 f_0}{P}$$

where P is the number of poles.

The rotor revolving at synchronous speed will of course cut the flux produced by the stator resulting from the current flowing of frequency f_0 when the charged capacitor is connected. The result will be merely to set up a cross field, and instead of the flux involved in determining the inductance L being a pulsating flux, it is now rotating. This rotating field, however, supports a voltage of the same frequency and magnitude as a pulsating flux of the same maximum amplitude. The voltage in either case is

$$E = K\phi \sin 2\pi f t$$

where K is a constant and t is time.

It is probably beside the point to discuss whether such a condition is stable; that is whether the capacitor discharges just as though the rotor had no conductors. The situation is complicated by the stator and rotor resistance always present in the practical case.

Now suppose the rotor is driven at a speed slightly above synchronous speed as previously defined. This means that if the stator flux continues to rotate at the frequency f_0 there is a slip resulting in low-(slip) frequency rotor current. Since the rotor conductors are pushing ahead, the slip current in the bars has a magnetizing effect. The effect of this will be to increase the flux ϕ_0.

Now this condition may be regarded as increasing the inductance of the stator winding. This in turn reduces the natural period of oscillation, and a new frequency of current through the capacitor exists; that is,

$$(2\pi f_1)^2 = \frac{1}{(L_0 + L_r)\,C}$$

where L_r is the effective increased inductance due to magnetizing effect of rotor current.

This means that the slip of the field as compared with rotor speed increases, which in turn enlarges the slip current and the magnetizing effect of the rotor conductors. A "vicious circle" results, until the machine either loads to saturation or the torque exceeds the capacity of the driver and the speed drops. Since the stator current is flowing at resonant frequency, it is limited only by the circuit resistance.

In many practical cases harmful results will appear, such as building up of voltage sufficient to cause failure of the capacitor, breakdown of generator insulation, or overheating of generator. In a capacitor type of motor with certain types of connections, circulating currents may be caused by this generating action, which produces a large negative torque preventing the motor from pulling up to speed.

It would seem desirable to have means available to control frequency of generator output, and output voltage. Perhaps the easiest method of controlling frequency is the use of a salient-pole rotor. This would also tend to control voltage build-up, since the "vicious circle" outlined previously would not exist.

Next, in order to have dependable build-up, a small d-c excitation or a permanent magnet might be introduced.

The net result is an a-c generator or magneto with a capacitor across the terminals or perhaps in series with the load to hold up or boost the delivered voltage. Such an arrangement is, of course, by no means new.

Very truly yours,
Charles T. Button (A'26)
Sales Engineer, The Holtzer-Cabot
Electric Co., Boston, Mass.

Personal Items

F. L. Hunt (A'05, F'17) director of economics and engineering of Western Massachusetts Companies, Greenfield, Mass., has been elected vice-president of that association and of each of its constituent utility companies, and assigned the duty of general charge of operations of those companies. Mr. Hunt was born at Delta, Iowa, in 1879, and was graduated from the University of Nebraska with the degree of bachelor of science in electrical engineering in 1902. Following his graduation he spent 3 years in the testing department of the General Electric Company, Schenectady, N. Y. In 1905 he was transferred to the Boston, Mass., offices of the General Electric Company, where he was in charge of construction work in New England, and later assistant district engineer. In 1913 Mr. Hunt accepted the position of chief engineer of the Turner Falls Power and Electric Company and allied companies in Greenfield, Mass., and in 1927 when Western Massachusetts Companies was formed, including the Turner Falls Power and Electric Company, United Electric Light Company, Pittsfield Electric Company, and the Greenfield Electric Light and Power Company (now Western Massachusetts Electric Company), Mr. Hunt was appointed director of economics and engineering of those companies. He has served the Institute as a member of the committees on protective devices, 1914–16 and 1919–29; standards, 1923–32; and meetings and papers (now technical program), 1926–28. Mr. Hunt is the author of several Institute papers.

A. C. Schwager (A'24, M'31) formerly chief engineer of the Pacific Electric Mfg. Corporation, San Francisco, Calif., has been elected vice-president in charge of engineering. Mr. Schwager, born in Switzerland in 1899, completed his general and technical education and began his professional career in that country as a technical assistant in the test laboratory of the Electric Manufacturing Company, at Oerlikon. Later, during 1922–23, he served as assistant professor at the Institute of Technology in Zurich. He came to the United States in 1923, whereupon he joined the staff of the Electrical Testing Laboratories, New York, N. Y., as a technical assistant on high-voltage cable research, but in the following year transferred his affiliation to the New York Edison Company, where he served as a draftsman on power-plant and substation design. During 1925–26 he continued the same type of work with the Pacific Gas and Electric Company, San Francisco, Calif. Since 1926 Mr. Schwager has been associated continuously with the Pacific Electric Mfg. Corporation, first as test engineer in charge of the test laboratory and successively as executive engineer in charge of the engineering department, as design engineer in charge of oil circuit breaker design, and as chief electrical engineer. In 1931 he was appointed chief engineer of the company. Mr. Schwager has contributed liberally to technical literature by means of articles in trade periodicals and through several papers presented before the Institute.

Walter Carr (A'14, M'17) who was elected a vice-president of the Connecticut Railway and Lighting Company, Bridgeport, in 1936, recently was elected a director of the company, and now is in charge of the company's operations. Mr. Carr was born October 27, 1888, at Fredericton, N. B., Canada, and was graduated from Stevens Institute of Technology with the degree of mechanical engineer in 1910. Upon graduation he entered the employ of the General Electric Company, Lynn, Mass., as a test engineer, and remained there for one year before returning to Fredericton to become superintendent of the municipal lighting plant of that city. In 1912 Mr. Carr accepted a position with the United Gas Improvement Company, Philadelphia, Pa., and remained for more than 24 years, during which period his work consisted of the design, construction, and operation of street railway and motor-coach facilities.

F. W. MacNeill (A'11, M'22) district sales engineer for the Canadian General Electric Company, Vancouver, B. C., recently was elected to the council of The Engineering Profession in British Columbia to represent the electrical engineers of the province. Mr. MacNeill was born at Ormond, Ont., Canada, in 1882, and received a diploma in mechanical and electrical engineering from the faculty of applied science of the University of Toronto in 1907. During the following year he pursued postgraduate work at the same institution and received the degree of bachelor of applied science. Upon graduation in 1908, Mr. MacNeill entered the employ of the Canadian General Electric Company, and for 2 years was engaged in electrical testing and design at the Peterboro, Ont., works of that company. In 1910 he was made sales engineer in the Toronto offices of that company, but in the same year was appointed district sales manager for Alberta and eastern British Columbia. He has held his present position as district sales engineer for the Province of British Columbia since 1917. Mr. MacNeill was chairman of the Institute's Vancouver Section during 1923–24.

E. H. Colpitts (A'11, F'12) vice-president of the Bell Telephone Laboratories, Inc., New York, N. Y., has retired from active service. Doctor Colpitts was born January 19, 1872, at Point du Bute, N. B., Canada, and received the degree of bachelor of arts at Mt. Allison College (1893) and Harvard University (1896); in 1897 he received the degree of master of arts at Harvard. He continued his work in the Harvard graduate school for $1^1/_2$ years, but received no further degree; however, in 1926 Mt. Allison College conferred upon him the honorary degree of doctor of laws. After terminating his graduate work in mathematics and physics he entered the employ of the American Bell Telephone Company, being engaged in research problems in telephone transmission. A few years later, when this department was merged with the engineering department of the American Telephone and Telegraph Company, Doctor Colpitts continued with the new company until 1907, when he was transferred to the engineering department of the Western Electric Company, New York. In 1917 he became assistant chief engineer of that company, and in 1924 was elected assistant vice-president of the American Telephone and Telegraph Company. He became vice-president of the Bell Telephone Laboratories in 1933. Doctor Colpitts has been granted many patents, and is the author of numerous technical papers. He served the Institute as a member of the committee on standards, 1916–17; telegraphy and telephony (now communication), 1919–24; and research, 1922–37. He is a member of the Institute of Radio Engineers, the American Physical Society, and several other technical organizations.

B. W. Dunkelburger, Jr. (A'36) formerly technician and supervisor in the visual instruction department of North Dakota State College, Fargo, now is principal of The Northwood (N. D.) High School. Mr. Dunkelburger received the degree of bachelor of science in education

F. L. HUNT

A. C. SCHWAGER

WALTER CARR

at North Dakota State College in 1936, and during his undergraduate training acted as assistant principal and dean of the Boys Agricultural and Mechanics Arts High School, conducted by North Dakota State College.

W. L. Whyte (A'35) until recently stationed at Ceará, Brazil, with the Ceará Tramway, Light, and Power Company, Ltd., recently accepted an appointment as technical adviser in electrical matters to the Uganda Government. Mr. Whyte has had broad experience in electrical construction and operation in Argentina, Brazil, Great Britain, and the Federated Malay States. He is a member of the Institution of Electrical Engineers (Great Britain).

B. E. Anderson (M'35) formerly assistant electrical engineer in the Public Works Department, United States Navy Yard, Mare Island, Calif., now is employed by the Phoenix Engineering Corporation, New York, N. Y. Mr. Anderson, a native (1896) of Colorado Springs, Colo., has had wide experience in public utility work in the United States and abroad.

Jack Delmonte (A'36) has resigned his position as junior electrical engineer at the naval aircraft factory, United States Navy Yard, Philadelphia, Pa., to accept a position as laboratory technician in the engineering research laboratories of the Firestone Tire and Rubber Company, Akron, Ohio.

W. A. Stelzer (A'34) who has been an electric dredge engineman, United States Engineers, Fort Peck, Mont., now is employed as a draftsman in the electrical engineering department of the Commonwealth and Southern Corporation, Jackson, Mich.

F. M. Farmer (A'02, F'13, director) vice-president and chief engineer, Electrical Testing Laboratories, New York, N. Y., has been appointed a member of the Institute's executive committee to fill the unexpired term of the late Junior Past-President E. B. Meyer.

J. S. Brown (A'23, M'31) who has been employed in the survey department of the Potomac Electric Power Company, Washington, D. C., now is employed in the electrical engineering department of the Duquesne Light Company, Pittsburgh, Pa.

H. W. Richter (A'36) formerly a designer for the Dormeyer Manufacturing Company, Chicago, Ill., now is employed as an electrical engineer for the Allen Electric and Equipment Company, Kalamazoo, Mich.

L. A. Helgesson (A'34) formerly assistant engineer in the steam heat department of the Northwestern Electric Company, Portland, Ore., has resigned to accept a position in the engineering department of L. R. Teeple Company, Portland.

R. L. Smith (M'34) formerly an electrical engineer for the Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., now is employed by the Stone and Webster Engineering Company, Boston, Mass.

L. B. Eckles (A'36) formerly an electrical designer for the Consumers Power Company, Jackson, Mich., recently accepted a position as associate engineer with the Iowa Agricultural Business Corporation Service, Des Moines.

J. K. Moore (A'36) who has been an electrical engineer for the Hydroelectric Commission of the State of Oregon, Salem, now is employed by the Eastern Oregon Light and Power Company, Baker.

E. J. Ramaley (A'32) formerly senior rodman, United States Bureau of Public Roads, Denver, Colo., now is engaged in research work at Battelle Institute, Columbus, Ohio.

I. E. Mouromtseff (A'25) research engineer, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., has been transferred to the lamp division of that company at Bloomfield, N. J.

Robert MacDonald (A'28) formerly power engineer for Ericcson Telephones, Ltd., Beeston, Nottingham, England, now is employed by the Western Electric Company, Kearny, N. J.

E. D. Lilja (A'31) formerly an electrical engineer with Barber-Colman Company, Rockford, Ill., now holds a similar position with the Woodward Governor Company, Rockford.

F. R. Marion (A'26) has been transferred from the operating engineering department of Electrical Research Products, Inc., New York, N. Y., to the Western Electric Company, Kearny, N. J.

Obituary

William Stanton Twining (A'05, M' 13) retired engineer, Ambler, Pa., died February 8, 1937. Mr. Twining was born February 20, 1865, near Titusville, Pa., attended Cornell University, and was graduated from Allegheny College in 1887, as a civil engineer. During the 3 following years he remained at Allegheny College as an instructor in chemistry and engineering, and in 1890 entered the railway engineering department of the Thomson-Houston Company at Boston, Mass., where his work consisted of power-station design and construction. In 1901 he was engaged as assistant engineer for the Union Railway Company and the Interborough Rapid Transit Company, New York, N. Y., and remained in that position until 1903, when he transferred his affiliation to the Peoples Traction Company, Philadelphia, Pa. In 1905 Mr. Twining was appointed chief engineer of that company and its successor, the Union Traction and Philadelphia Rapid Transit Company, in which position he was in general charge of all engineering work. From 1910 to 1914 he served as engineering manager for the consulting engineering firm of Ford, Bacon, and Davis, New York, N. Y. He then returned to Philadelphia to become the first director of transit of that city. Mr. Twining retired from active service in 1925.

Eugene L. Alexander (A'35) formerly an electrical draftsman for the New York (N. Y.) Rapid Transit Corporation, died November 1, 1936, according to word just received at Institute headquarters. Mr. Alexander was born October 1, 1882, at Tiflis, Russia, and received the degree of electrical engineer from the University of Liege (Belgium) and the Electrical Institute of Emperor Alexander III (Russia) in 1908 and 1910, respectively. Following his graduation he was appointed assistant superintendent of the electrical department of the Steel, Locomotive, and Shipbuilding Works, Soromovo, Russia, and remained in that capacity until 1914, when he was made superintendent of the electrical power plant and assistant superintendent of the electrical department in the Metallurgical Corporation of Nicopol Marioupol. During the year 1918–19 Mr. Alexander was superintendent of the municipal electric plant of the City of Marioupol, Russia, and in the following year he accepted a position as assistant superintendent of a central station of the Compagnie Ottomane d' Electricitè, Constantinople, Turkey. In 1925 he came to the United States and entered the employ of The New York (N. Y.) Edison Company as an electrical draftsman. In 1928 he transferred to the New York Rapid Transit Company in a similar position.

Walter Edward Bare (A'29) general commercial manager of the Southern Bell Telephone and Telegraph Company, Atlanta, Ga., died February 5, 1937. Mr. Bare was born September 22, 1882, at Lexington, Va., and was educated in private schools in Florence, Ala. He entered the employ of the Southern Bell Telephone and Telegraph Company as a lineman in 1903 and served that company continuously, except for a brief service in the United States Army during the World War. From 1905 to 1916 he acted as manager of various local plants of the company, and in 1919 was promoted to district manager in the Montgomery, Ala., offices. During 1921–23 he held a similar position in the Birmingham offices before being appointed Alabama state manager for the company. Mr. Bare became commercial manager in 1930.

Frederick A. Scheffler (A'93, M'96, F'12, member for life) retired electrical engineer, formerly connected with The Babcock & Wilcox Co., New York, N. Y., died

February 23, 1937. Mr. Scheffler was born December 20, 1858, at Galion, Ohio, and was graduated from the Paterson (N. J.) Seminary in 1871, following which he was associated briefly with several companies, including the Rhode Island Locomotive Works, Brown and Sharpe, and the Harris Corliss Engine Company, before joining the Edison Electric Light Company, New York, N. Y., in 1881. He was placed in charge of the engineering department of the Edison company, and in that capacity designed an electric locomotive used in experimental work by Thomas A. Edison (A'84, M'84, HM'28, John Fritz Medalist '08). In 1885 Mr. Scheffler became superintendent of the Erie City Iron Works, Erie, Pa., which position he held for 5 years before resigning to become acting general superintendent of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., in 1889. Later he served as general superintendent of the Brush Electric Company (1891–93), the Sprague Electric Company (1899–1900), and the Marine Engineering and Machinery Company (1902–04). Mr. Scheffler was affiliated with The Babcock & Wilcox Co. and its subsidiary companies for many years. He served the Institute as a member of the committee on power stations from 1916 to 1919 and from 1922 to 1935, and as a member of the special committee on the Edison Memorial during 1932 and the Edison Medal committee, 1913–18, 1922–27, and 1930–33. He was a member of The American Society of Mechanical Engineers.

Membership

Recommended for Transfer

The board of examiners, at its meeting on March 17, 1937, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Baldwin, R. L., consulting engineer, Burns and McDonnell Engineering Company, Kansas City, Mo.
Conrad, Frank, assistant chief engineer, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
2 to Grade of Fellow

To Grade of Member

Anderson, C., headquarters sales and application, instruments and measuring devices, Westinghouse Electric and Manufacturing Company, Newark, N. J.
Balch, E. C., chief engineer, Michigan Bell Telephone Company, Detroit, Mich.
Balet, J. W., engineer, Consolidated Edison Company of New York, Inc., New York, N. Y.
Boehne, E. W., design engineer, General Electric Company, Philadelphia, Pa.
Bronaugh, J., sales representative, Allis-Chalmers Manufacturing Company, Richmond, Va.
Carroll, J. S., associate professor, electrical engineering department, Stanford University, Calif.
Gardner, J. B., electrical engineer, Chicago, Burlington and Quincy Railroad Company, Chicago, Ill.
Joboolian, E., squad boss, Gibbs and Hill, New York, N. Y.
Johnson, G. E., chief engineer and general manager, The Central Nebraska Public Power and Irrigation District, Hastings, Neb.
King, R. T., industrial power representative, Public Service Electric and Gas Company, Trenton, N. J.
Logan, K. H., senior electrical engineer, National Bureau of Standards, Washington, D. C.
McCormack, J. E., distribution engineer, New York and Queens, Electric Light and Power Company, Flushing, N. Y.
Michaels, A. P., consulting engineer, A. P. Michaels Engineering Firm, Orlando, Fla.
Walker, E. W., proprietor, E. W. Walker, Birmingham, England.
Zangler, R. M., standardization of mfg. practices and engineering data, Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.
15 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before April 30, 1937 or June 30, 1937, if the applicant resides outside of the United States or Canada.

Abramowitz, A., 579 East 140th Street, New York, N. Y.
Adams, J. T. (Member), Public Service Company of Oklahoma, McAlester, Okla.
Alenius, E., Bell Telephone Laboratories, Inc., New York, N. Y.
Allen, T. O., Humble Oil and Refining Company, Anahuac, Texas.
Anders, R. D., Philadelphia Electric Company, Phoenixville, Pa.
Anderson, C. B., 313 Public Service Building, Tulsa, Okla.
Angier, J. F., National Bureau of Standards, Washington, D. C.
Anthony, B. M., Tennessee Valley Authority, Wilson Dam, Ala.
Arnn, E. L., General Electric Company, Philadelphia, Pa.
Aruck, M., Bell Telephone Laboratories, Inc., New York, N. Y.
Babcock, K. L., Underwood Elliott Fisher Company, Hartford, Conn.
Babin, B. P., Westinghouse Electric & Manufacturing Company, New Orleans, La.
Bader, R. D., Philadelphia Storage Battery Company, Philadelphia, Pa.
Bailey, A. (Member), American Telephone and Telegraph Company, New York, N. Y.
Balfour, M. W., Public Service Company of Northern Illinois, Chicago, Ill.
Banks, J. F., Commonwealth Edison Company, Chicago, Ill.
Barnes, C., Jr., 1153 N. Dearborn Street, Chicago, Ill.
Barrett, W. G., 10 West 90th Street, New York, N. Y.
Basore, N. D., Public Service Company of Oklahoma, Hartshorne, Okla.
Baum, D. C., 5001 Goodridge Avenue, Riverdale-on-Hudson, N. Y.
Bazak, H. V., Consolidated Edison Company of New York, Inc., New York, N. Y.
Beatty, F., University of Kentucky, Lexington, Ky.
Beck, J. M., Jr., Westinghouse Electric and Manufacturing Company, Wichita, Kans.
Behm, T. R., Syracuse Lighting Company, Syracuse, N. Y.
Behrens, H. J., Consolidated Edison Company of New York, Inc., New York, N. Y.
Bejarano, J. R., 87 Grove Street, Lynbrook, N. Y.
Bell, R. O., 1501 South 77th Street, Milwaukee, Wis.
Benson, B. T., Foreign and Domestic Commerce, Washington, D. C.
Bernard, W. B., 1407 West University Avenue, Gainesville, Fla.
Bingham, W. H. (Member), Westinghouse Electric Supply Company, New York, N. Y.
Birmingham, Paul V., 1285 Oak Grove Avenue, Burlingame, Calif.
Bischof, L. J., General Electric Company, New York, N. Y.
Bishop, R. H. (Member), Public Servic Company of Oklahoma, Tulsa, Okla.
Blom, L. A., 2306 N. Knox, Chicago, Ill.
Boehr, J. W., Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Borton, J. R., Puget Sound Power and Light Company, Seattle, Wash.
Bossard, G. E., General Kontrolar Company, Inc., Dayton, Ohio.
Bottum, E. L., Carnegie Illinois Steel Corporation, Gary, Ind.
Boyd, A. G., General Electric Company, Schenectady, N. Y.
Bradstock, M. C., General Electric Company, Cleveland, Ohio.
Brazeel, J. P., Public Service Company of Oklahoma, Okemah, Okla.
Brewer, L. G., Montana Power Company, Havre, Mont.
Brewer, R. D., Ford Motor Company, Dearborn, Mich.
Bridegam, W. J., E. M. Gilbert Engineering Corporation, Reading, Pa.
Brignac, E. M., Industrial Electric Company, New Orleans, La.
Brody, E. W., Line Material Company, South Milwaukee, Wis.
Brown, J. G., General Electric Company, Schenectady, N. Y.
Brown, J. T., Jr., Carolina Power and Light Co., Raleigh, N. C.
Burleigh, C. LeM., Jr., Harvard Business School, Boston, Mass.
Campbell, R. P., Tennessee Valley Authority, Wilson Dam, Fla.
Carioni, H. M., Canadian Westinghouse Company, Ltd., Hamilton, Ont.
Carlberg, H. A., Wisconsin Public Service Corporation, Green Bay, Wis.
Carroll, D. R., Bell Telephone of Pennsylvania, Pittsburgh, Pa.
Chambers, M. A., Standard Oil Company, Shreveport, La.
Cherry, J. S., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Clough, F. P., Y. M. C. A., 8 East 3rd Street, New York, N. Y.
Cobert, C. S., Clark Controller Company, Cleveland, Ohio.
Coho, O. C., Jr., General Electric Company, Schenectady, N. Y.
Coleman, I. M., 581 Academy Street, New York, N. Y.
Colquhoun, W. H., in care of Maurice R. Scharff, New York, N. Y.
Connolly, D. E., 1738 Webster Avenue, New York, N. Y.
Contardi, A., Jr., 959 Middlesex Avenue, Metuchen, N. J.
Cooper, D. T., Brown Instrument Company, Philadelphia, Pa.
Crooks, W. E., 41 Duggan Avenue, Toronto, Ont., Canada.
Crosby, T. H., Canadian Westinghouse Company, Ltd., Vancouver, B. C., Canada.
Dalrymple, H. C., 46 Colony Drive East, West Orange, N. J.
Darrah, M. D., 4417 Swiss Avenue, Dallas, Texas.
Deardorff, R. W., Pacific Telephone and Telegraph Company, Portland, Ore.
DeBlois, W., Lincoln Electric Company, Boston, Mass.
deCarrera, R., General Electric Company, Schenectady, N. Y.
Degentesh, H. E., Square D Company, New York, N. Y.
Dermond, F., Bell Telephone Laboratories, Inc., New York, N. Y.
Dickinson, H. C., General Electric Company, Lynn, Mass.
Dingman, J. E. (Member), American Telephone and Telegraph Co., New York, N. Y.
Doede, H. C., Swift and Company, Chicago, Ill.
Doherty, J. F., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Dollins, C. B., Jr., Tennessee Valley Authority, Wilson Dam, Ala.
Dubsky, F. H., Commonwealth Edison Company, Chicago, Ill.
Dudley, R. B., The Jeffrey Manufacturing Company, Columbus, Ohio.
Duncan, A. H., Westinghouse Electric and Manufacturing Company, Wilkinsburg, Pa.
Ebert, K. W., 776 N. Cass Street, Milwaukee, Wis.
Eckert, J. D., Box 67, Flagler, Colo.
Ecklund, R. A., C. T. Main, Inc., Boston, Mass.
Eddy, W. L., Western Electric Company, Chicago, Ill.
Ellicott, C. R., Jr., Westinghouse Electric and Mfg. Co., Wilkes-Barre, Pa.
Ellsworth, C. E., Selectric Products Corporation, Louisville, Ky.
Elwood, E. S., Jr., General Electric Company, Schenectady, N. Y.
Emmons, P. A., Jr., 1233 North President Street, Jackson, Miss.
English, G. T., Triad Radio Tube Manufacturing Company, Pawtucket, R. I.
Ericson, A. E., 3950 North Farwell Avenue, Milwaukee, Wis.
Estoppey, R. F., Weston Electrical Instrument Corporation, Newark, N. J.
Ewert, A. C., Radio Station WMFJ, Daytona Beach, Fla.
Fagerlund, A. C., 2918 Jefferson Avenue, Cincinnati, Ohio.
Fallon, R. C., General Electric Company, Schenectady, N. Y.
Falls, O., General Electric Company, Pittsfield, Mass.
Feinberg, E., 3255 Cortland Avenue, Detroit, Mich.
Feiner, J. S., 551 E. 178th Street, New York, N. Y.
Fickel, L. V. (Member), Westinghouse Electric and Manufacturing Company, Tulsa, Okla.
Flagg, L. F., W. E. Kingswell, Inc., Washington, D. C.
Fluke, J. M., General Electric Company, Schenectady, N. Y.

Foley, R. B., General Electric Supply Company, New York, N. Y.
Forman, W. B., Westinghouse X-Ray Company, Pittsburgh, Pa.
Forsyth, J. E., Canadian Controllers, Ltd., Toronto, Ont., Canada.
Francis, F. W., Zerbe Township Public School, Trevorton, Pa.
Frank, D. W., Southwestern Light and Power Company, Lawton, Okla.
Freas, R. L., Pennsylvania State College, Conshohocken, Pa.
Friedman, H., Mackay Radio and Telephone Company, New York, N. Y.
Froling, R. O., General Electric Company, Pittsfield, Mass.
Fuller, A. L., Oklahoma Gas and Electric Company, Oklahoma City, Okla.
Fuller, M. A., Miller Rubber Company, Inc., Akron, Ohio.
Fullman, J. B., Westinghouse Electric and Manufacturing Co., Sharon, Pa.
Gallagher, J. J., Narragansett Electric Company, North Swansea, Mass.
Gardner, E. M., New York Telephone Company, New York, N. Y.
Gerhold, R. A., Signal Engineering and Manufacturing Company, New York, N. Y.
Gilreath, W. W., 2510 San Antonio Street, Austin, Texas.
Golub, E., 405 Quentin Road, Brooklyn, N. Y.
Gould, G. G., Porcelain Products, Inc., Parkersburg, W. Va.
Gramstedt, G. M. E., Hayg Electric Company, New York, N. Y.
Green, G. M., Black, Sivalls and Bryson, Inc., Kansas City, Mo.
Grigg, E. G., General Electric Company, Philadelphia, Pa.
Groenewold, A. W., Public Service Company of Oklahoma, Tulsa, Okla.
Guggenbuehler, C. R., Wagner Electrical Corporation, St. Louis, Mo.
Gulick, H. E., 718 North Louise Street, Glendale, Calif.
Hackenjost, H. F. (Member), Tennessee Valley Authority, Wilson Dam, Ala.
Hanson, C. F. (Member), Irvington Varnish and Insulator Company, Irvington, N. J.
Hart, L. B., Ohio Power Company, Coshocton, Ohio.
Hammer, O. S. C., Tennessee Valley Authority, Knoxville, Tenn.
Hamrick, G. W., Florida Power and Light Company, Dania, Fla.
Harry, W. R., Bell Telephone Laboratories, Inc., New York, N. Y.
Haun, R. C., Public Service Company of Oklahoma, Stigler, Okla.
Haupt, G. H., Samson-United Corporation, Rochester, N. Y.
Hebert, M., Jr., Gulf Oil Corporation, Port Arthur, Texas.
Henderson, R. H., Minneapolis Honeywell Company, New York, N. Y.
Henkes, G., Jr., Public Service Company of Oklahoma, Henryetta, Okla.
Herweh, A. C., 3739 Woodburn Avenue, Cincinnati, Ohio.
Heyburn, R. D., Firestone Tire and Rubber Company, Akron, Ohio.
Higginson, H., 414 N. Kilkea Drive, Los Angeles, Calif.
Hildebrandt, J. P., Humble Oil and Refining Company, Harlingen, Texas.
Hively, H. L., Jones and Laughlin Steel Corporation, Pittsburgh, Pa.
Hobson, C., General Electric Company, Pittsfield Mass.
Hoch, E. G., Jr., Electric Heating Equipment Company, Philadelphia, Pa.
Holston, S. C., Liebel Flarsheim Company, Cincinnati, Ohio.
Hopper, F. E., Crocker Wheeler Electric Manufacturing Company, Ampere, N. J.
Hoss, W. B. (Member), Oklahoma Power and Water Company, Sand Springs, Okla.
Howmiller, S., Harnischfeger Manufacturing Company, Milwaukee, Wis.
Huff, P. D., Duke Power Company, Salisbury, N. C.
Hunter, H. H., Public Service Commission of West Vriginia, Charleston, W. Va.
Hunter, M. V., Bell Telephone Laboratories, Inc., New York, N. Y.
Husted, E. W., Michigan Associated Telephone Company, Muskegon, Mich.
Hutson, M. B., Industrial Electric Company, New Orleans, La.
Insull, F. W. (Member), Southwestern Light and Power Company, Tulsa, Okla.
Jacobs, Y., 626 Garrard Street, Covington, Ky.
James, J. R., James G. Biddle Company, Philadelphia, Pa.
Jeffers, G. N., R. R. No. 1, Chilo, Ohio.
Johnson, F. B. (Member), Commonwealth Edison Company, Chicago, Ill.
Johnson, J. H., 826—43rd Street, Brooklyn, N. Y.
Johnson, W. B., Ohio Brass Co., Mansfield, Ohio.
Jones, A. L., Jr. (Member), General Electric Company, Tulsa, Okla.
Jones, R. H., Hartford, Electric Light Company, Hartford, Conn.
Kanyuck, R. A., Bethlehem Steel Company, Sparrows Point, Md.
Kay, J. S., Pacific Gas and Electric Company, Chico, Calif.
Keating, C. J., New York, Telephone Company, New York, N. Y.
Keator, E. C., South Fallsburg, N. Y.
Keck, J. N., Moloney Electric Company, St. Louis, Mo.
Kehoe, W., City Light and Water Utilities, Fort Wayne, Ind.
Kern, P. H., Western Electric Company, Chicago, Ill.
Kerr, W. E. (Member), Pennsylvania Transformer Company, Pittsburgh, Pa.
Kessel, R. L., Cline Electric Manufacturing Company, Chicago, Ill.
Keyser, A. G., Jr., 1777 Lanier Place, N. W., Washington, D. C.
Kidd, J. A. I., Canadian General Electric, Peterborough, Ont., Can.
Klebanoff, J. H., State Highway Planning Survey, Sacramento, Calif.
Klein, M., Otis Elevator Co., Yonkers, N. Y.
Knost, C. P. (Member), Moloney Electric Co., New Orleans, La.
Kopenitsi, C. T., Oilgear Company, Milwaukee, Wis.
Kralosky, F. B., 2622 Bartold Street, N. S., Pittsburgh, Pa.
Kulikowski, E. F., Jensen Radio Manufacturing Co., Chicago, Ill.
Kyes, J. M., 1946 Washington Street, San Francisco, Calif.
Lane, R. K. (Member), Public Service Company of Oklahoma, Tulsa, Okla.
Lantz, L. E., Jr., Jacksonburg, W. Va.
Lawson, S. A., Gustav Hirsch Organization, Columbus, Ohio.
Lee, H. B., Rural Electrification Administration Washington, D. C.
Lefthes, N., 11 Ward Street, Salem, Mass.
Legg, V. E. (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Lenhardt, W. C., Bethlehem Steel Company, Cornwall, Pa.
Levine, M. E., Tung-Sol Lamp Works, Newark, N. J.
Lobosco, R. R., Linde Air Products Company, Newark, N. J.
Lovoff, A., 3496 Anderdon Street, Detroit, Mich.
Ludden, J. H., 80 Mill Street, Athens, Ohio.
Lundgren, L. O., Kennecott Wire and Cable Company, Phillipsdale, R. I.
MacAllister, C. C., General Electric Company, Lynn, Mass.
MacKay, E. L., General Electric Company, Schenectady, N. Y.
Mansfield, T. E. (Member), Oklahoma Power and Water Company, Sand Springs, Okla.
Marshall, M. B., Jr., General Electric Company, Erie, Pa.
Martin, W. L., Triad Manufacturing Company, Pawtucket, R. I.
Martini, J. A., American Telephone and Telegraph Company, New York, N. Y.
Matheo, M., Consolidated Edison Company, New York, N. Y.
Matzinger, J. R., American Electric Switch Corporation, Minerva, Ohio.
May, M. H., Interstate Power Company, Albert Lea, Minn.
Mayer, J. A., Graybar Electric Company, Cleveland, Ohio.
Mayers, J. H., 917 Druid Hill Avenue, Baltimore, Md.
McArthur, D., General Electric Company, West Lynn, Mass.
McCormack, C. M., Phelps-Dodge Copper Products Corporation, Yonkers, N. Y.
McCrary, J. H. (Member), Public Service Company of Oklahoma, Tulsa, Okla.
McDowell, E. P., General Electric Company, Schenectady, N. Y.
McLeod, G. R., General Electric Company, West Lynn, Mass.
Mearns, W. J., Continental-Diamond Fibre Company, Bridgeport, Pa.
Messler, W. H., Winchester Repeating Arms, New Haven, Conn.
Michaelis, J. L., Pittsburgh Plate Glass Company, Barberton, Ohio.
Miller, R. E., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Mooney, V. J., General Electric Company, Schenectady, N. Y.
Morgan, L. W., Commonwealth Edison Company, Chicago, Ill.
Morris, R. V., Gary Heat, Light and Water Company, Gary, Ind.
Morrison, H. A., Central Nebraska Public Power and Irrigation District, Hastings, Neb.
Moss, A. G. (Member), Public Service Company of Oklahoma, McAlester, Okla.
Mostrom, J., Phillips Petroleum Company, Bartlesville, Okla.
Motz, C. A., General Electric Company, Schenectady, N. Y.
Murphy, J. T., Shell Petroleum Corporation, Plaquemine, La.
Nauert, A. G., American Telephone and Telegraph Company, New York, N. Y.
Nelson, C. T., Public Service Company of Oklahoma, Okmulgee, Okla.
Nickerson, G., Texas Development Corporation, Lafitte, La.
Nimmer, F. W., Ohio Edison Company, Akron, Ohio.
Norton, T. P., 3 Bradford Street, Salem, Mass.
Olsta, E., Consolidated Edison Company of New York, Inc., New York, N. Y.
O'Meara, F. E. (Member), Westinghouse Electric & Manufacturing Company, Tulsa, Okla.
Pacanovsky, G. J., 7908 Halle Avenue, Cleveland, Ohio.
Papp, A., Jr., General Electric Company, Philadelphia, Pa.
Park, A. J., Graybar Electric Company, Cleveland, Ohio.
Parker, C. V., Bell Telephone Laboratories, Inc., New York, N. Y.
Parker, F. D., 106 Northern Avenue, New York, N. Y.
Parker, R. S., c/o H. B. Parker, 602 East Broadway, Madisonville, Ky.
Paterson, J. M., 7200—28th Avenue, N. W., Seattle, Wash.
Patterson, E. F., General Electric Company, Tulsa, Okla.
Patterson, G. W. (Member), Patterson Electric, Ltd., Toronto, Ont., Canada.
Pauler, E. A., Electric Storage Battery Company, Chicago, Ill.
Pearce, T. C. (Member), Potomac Electric Power Company, Washington, D. C.
Pence, I. E., 1120 North Milwaukee Street, Milwaukee, Wis.
Perlman, I., Air-King Radio Products Company, Brooklyn, N. Y.
Perrine, T. F., Jr., Jersey Central Power and Light Company, Allenhurst, N. J.
Perry, F. W., Jr., Brown and Sharpe Manufacturing Company, Providence, R. I.
Perry, W. J. (Member), Public Service Company of Oklahoma, Weleetka, Okla.
Perschbacher, H. V., Milwaukee Electric Railway and Light Company, Milwaukee, Wis.
Person, H. O., State Wide Highway Planning Survey, Howard, S. Dak.
Phillips, G. H., Georgia Power Company, Atlanta, Ga.
Phillips, N. W., Alabama Power Company, Decatur, Ala.
Phinney, J. A., Hugo District Public Service Company of Oklahoma, Hugo, Okla.
Pobst, J. W., General Electric Company, Schenectady, N. Y.
Post, L. E., New Jersey Bell Telephone Company, Newark, N. J.
Pryor, T. S., Southern Cotton Oil Company, Montgomery, Ala.
Rand, R. V., Box 237, Bismarck, N. D.
Regan, P. G., Minneapolis Honeywell Regulator Company, Boston, Mass.
Reichel, A. N., Western Electric Company, Kearny, N. J.
Rhodes, C. F., Templeton-Kenly and Company, Ltd., Chicago, Ill.
Rice, W. O., West Penn Power Company, Springdale, Pa.
Ridgway, D. P., Robbins & Myers, Inc., Springfield, Ohio.
Roberts, C. F., Jr., Texas Electric Service Company, Wichita Falls, Texas.
Roberts, R. C., Tennessee Valley Authority, Wilson Dam, Tenn.
Rothschild, G. R., Republic Flow Meters Company, Chicago, Ill.
Ruffle, L. E., Federal Shipbuilding and Dry Dock Company, Kearny, N. J.
Ruonavar, W. T., Ford Motor Company, Dearborn, Mich.
Rushmer, R. H., General Electric Company, Fort Wayne, Ind.
Russell, W. J. (Member), Westinghouse Electric & Manufacturing Company, Mansfield, Ohio.
Ryan, G. D. (Member), 39 Arcade Building, Columbia, S. C.
Rylander, L. F. (Member), Public Service Company of Oklahoma, Tulsa, Okla.
Salton, H. D. (Member), Pennsylvania Transformer Company, Pittsburgh, Pa.
Saunders, B. W., Narragansett Electric Company, Providence, R. I.
Sauter, B. W., RCA Radiotron, Harrison, N. J.
Saveland, W. T., Jr., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Scattergood, E. R., Tennessee Valley Authority, Wilson Dam, Ala.
Schaefer, D. A., Indiana Bell Telephone Company, Indianapolis, Ind.
Schene, M. M., Public Service Company of Oklahoma, McAlester, Okla.
Schmidt, V. W. J., Cutler Hammer Inc., Milwaukee, Wis.
Schmitz, J. M., American Telephone and Telegraph Company, New York, N. Y.
Schumacher, H., Atlantic Gas and Electric Appliance Company, Los Angeles, Calif.
Schwan, C. F., Apex Electrical Manufacturing Company, Cleveland, Ohio.
Schweers, C. W., Allis-Chalmers Manufacturing Company, New Orleans, La.
Sealy, W. J., Canadian Railroad Service, Toronto, Ontario, Canada.
Segebarth, R. A., 1141 Ardsley Road, Schenectady, N. Y.
Seifried, D. B., F. C. Frederick Company, Summit Park, Spring Valley, N. Y.
Sepavich, V. F. P., 69 Harrison Street, Worcester, Mass.
Shaffer, J. A., Jones and Laughlin Steel Corporation, Pittsburgh, Pa.
Sharp, R. M., American Can Company, Newark, N. J.
Sheftelman, E. H., Automatic Diesel Electric Company, New York, N. Y.
Sherlin, G. C., Jr., Southwestern Bell Telephone Company, Little Rock, Ark.
Shew, W. W., General Electric Company, Schenectady, N. Y.
Shimer, R. B., Kenyon Transformer Company, New York, N. Y.
Shinn, G. H., Gibbs and Cox, Inc., New York, N. Y.
Shively, R. DeW., The B. F. Goodrich Company, Akron, Ohio.

Shumard, C. C. (Member), R. C. A. Manufacturing Company, Harrison, N. J.
Shutko, F. W., Jr., Detroit Edison Company, Trenton, Mich.
Siegel, E. M., Westinghouse X Ray Company, New York, N. Y.
Simons, R. L., Carolina Power and Light Company, Raleigh, N. C.
Simpson, J. L., Jr., Georgia Power Company, Athens, Ga.
Skina, F. A., 626 Ash Street, Moscow, Idaho.
Slemmer, W. E., Public Service Company of Oklahoma, Tulsa, Okla.
Smith, A. J., General Electric Company, Schenectady, N. Y.
Smith, H. G., Cornell University, Ithaca, N. Y.
Smith, R. G., General Electric Company, Tulsa, Okla.
Smith, W. J., Houston Armature Works, Houston, Texas.
Snyder, C. J., Indiana and Michigan Electric Company, South Bend, Ind.
Spangler, W. H., 240 North Meridian Street, Indianapolis, Ind.
Spitzglass, A. F. (Member), Republic Flow Meters Company, Chicago, Ill.
Spooner, E. K., Allis-Chalmers Manufacturing Company, Norwood, Ohio.
Stonestreet, N. V. (Member), Suburban Resettlement, Washington, D. C.
Strobel, H. C., Potomac Electric Power Company, Washington, D. C.
Sutherland, A. H., Public Utility Engineering and Service Corporation, Chicago, Ill.
Tarvin, E. B., Public Service Company of Oklahoma, Okmulgee, Okla.
Taussig, O. C., New York Power and Light Corporation, Schenectday, N. Y.
Taylor, H. C., Houston Lighting and Power Company, Houston, Texas.
Teague, T. S., General Electric Company, Schenectady, N. Y.
Teigen, T. N., Fairbanks, Morse and Company, Beloit, Wis.
Teller, W. A., American Telephone and Telegraph Company, New York, N. Y.
Templeton, L. O., Pacific Gas and Electric Company, San Jose, Calif.
Tholke, J. G., 480 Lexington Avenue, New York, N. Y.
Thomas, C. W. (Member), Public Service Company of Oklahoma, Bartlesville, Okla.
Thorpe, J., American Telephone and Telegraph Company, New York, N. Y.
Topf, S. B., Premier Electric Motor Company, New York, N. Y.
Tuepker, D. J., Public Service Company of Oklahoma, Tulsa, Okla.
Unholtz, K., 3536—8th Avenue, Los Angeles, Calif.
Upley, A. S., Chase-Shawmut Company, Newburyport, Mass.
Van Allen, W. G., 920 Livingston Avenue, New Brunswick, N. J.
Van Zeeland, F. J., Milwaukee School of Engineering, Milwaukee, Wis.
Vladikov, E., c/o Mr. Linero, 2115–8th Avenue, New York, N. Y.
Wagner, D. A., Cutler Hammer, Inc., Milwaukee, Wis.
Wald, G. E. (Member), Mortgage Commission Servicing Corporation, New York, N. Y.
Walsh, J. E., Bethlehem Steel Company, Sparrows Point, Md.
Ward, P. A., General Electric Company, Bloomfield, N. J.
Ward, T. V. (Member), Room 11, District Building, Washington, D. C.
Warner, D. F., General Electric Company, Schenectady, N. Y.
Wasilchuk, S., Western Electric Company, Kearny, N. J.
Watson, S. R., Jr., Carolina Power and Light Company, Marion, S. C.
Weaver, C. H., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Weber, J. A., New York, Power and Light Corporation, Albany, N. Y.
Wellons, R. S., Columbia University, New York, N. Y.
Welsch, G., Knapp Monarch Company, St. Louis, Mo.
Wentz, J. K., General Electric Company, Schenectady, N. Y.
Werner, H. F., Jr., Equitable Equipment Company, Inc., New Orleans, La.
Wetzel, J. J., Chrysler Corporation, Detroit, Mich.
Wheeler, W. M., General Electric Company, Pittsfield, Mass.
Whinery, W. D., Jr., General Electric Company, Pittsfield, Mass.
Whittenton, J. M., General Electric Company, Lynn, Mass.
Wiley, B. F., Phillips Petroleum Company, El Campo, Texas.
Wilsey, H. R., 48 Caroline Road, Upper Montclair, N. J.
Wilson, W. V., 480 Lexington Avenue, New York, N. Y.
Winslow, R. C., Automatic Diesel Electric Company, New York, N. Y.
Winterhalter, F. M., Allis-Chalmers Manufacturing Company, Norwood, Ohio.
Wood, J. N., Kansas State College, Manhattan, Kans.
Wrensch, B. E., 2945 North 4th Street, Milwaukee, Wis.
Wulfken, A. J., 1050—79th Street, Brooklyn, N. Y.
Wyman, J. H., Triad Manufacturing Company, Inc., Pawtucket, R. I.
Young, D. L., 1050 Mar Vista Avenue, Pasadena, Calif.
Zappo, N. W., The Teleregister Corporation, New York, N. Y.
Zindar, L. J., Cutler Hammer, Inc., Milwaukee, Wis.
Zinser, H. J., Heyer Products Company, Inc., Belleville, N. J.

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Foreign

Bonilla, R. B., 250 David Street, Manila, P. I.
Chang, P. F., Shanghai Power Company, Shanghai, China.
Dahlby, G. O. H., ASEA, Vasteras, Sweden.
de Velasco, J. F. (Member), Rio Grandense Light and Power Syndicate Ltd., Brazil, S. A.
Elliott, J. S. (Member), Hoover Electric Cleaner Company, Perivale, Greenford, Middlesex, England.
Mier, M. L., P. O. Box 471, San Juan, Puerto Rico.
Mohindra, S. L., North Western Railway, Scheranpur, India.
Nardi, M., Soc. Meridionale di Elettricitá, Naples, Italy.
Oliphant, W. D., British Electrical and Allied Industries Research Association, London, W. C. 2, England.

9 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Godoy, Ernesto R., Cia. Tel. y Tel. Mex., 16 de Septiembri No. 13, Mexico, D. F., Mex.
Hale, Edward E., Public Service Commission of New York, 80 Centre St., New York, N. Y.
Little, Leroy C., 3414—17th St., N., Cherrydale, Va.
Moore, Everett, 821 Sunset Blvd., Los Angeles, Calif.
Nash, G. H., 2-A Holland Road, London W.14, England.
Peach, Paul S., Upperville, Va.
Pollastro, John B., Helper, Utah.
Sawyer, Fred E., 811 E. Wisconsin Ave., Milwaukee, Wis.
Wickel, F. A., Pier 42, Dollar S. S. Lines, San Francisco, Calif.

9 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

ELECTRON TUBES in INDUSTRY. By K. Henney. 2nd edition. New York and London, McGraw-Hill Book Company, 1937. 538 pages, illustrated, 9x6 in., cloth, $5.00. Discusses the practical uses of thermionic and light-sensitive tubes outside the communication field.

ELEMENTS of ELECTRICITY. By W. Esty, R. A. Millikan, and W. L. McDougal. Chicago, American Technical Society, 1937. Illustrated, 9x6 in., cloth, $2.00. A textbook for beginners.

INTRODUCTORY STUDY of ELECTRICAL CHARACTERISTICS of POWER and TELEPHONE TRANSMISSION LINES. By F. W. Norris and L. A. Bingham. Scranton, Pa., International Textbook Company, 1936. 272 pages, illustrated, 9x5 in., leather, $2.50. Adaptable to an introductory course in the principles of electrical transmission. Aims to develop the student's ideas of the electric and magnetic fields and his ability to deal with circuits involving distributed constants.

JONES RADIO HANDBOOK. By F. C. Jones. 1937 edition. San Francisco, Pacific Radio Publishing Company, 1936. 456 pages, illustrated, 9x6 in., paper, $1.50. Presents the theory of radio communication and gives practical instruction upon the construction of transmitters and receivers, and radio-therapeutic apparatus; intended for the radio amateur.

(KEMPE'S) ENGINEER'S YEAR-BOOK of Formulae, Rules, Tables, Data, and Memoranda for 1937, 43rd Annual Issue, revised by L. St. L. Pendred. London, Morgan Brothers, 1937. 2,676 pages, illustrated, 7x5 in., leather, 31s. 6d. Deals with every phase of engineering and affords a survey of modern practice.

OUTLINE of the HISTORY of MATHEMATICS. By R. C. Archibald. 3rd edition. Oberlin, Ohio, Mathematical Association of America, Inc. 62 pages, 9x6 in., paper, $0.50. A sketch of the development of mathematics based upon 2 lectures delivered in 1931 at a summer school for engineering teachers organized by the Society for the Promotion of Engineering Education.

PROCEDURE HANDBOOK of ARC WELDING, DESIGN, and PRACTICE. 4th edition. Cleveland, Ohio, Lincoln Electric Company, 1936. 819 pages, illustrated, 9x6 in., leather, $1.50. Discusses in a practical manner the equipment and technique of arc welding, the design of arc-welded machinery and structures and the applications of arc welding in manufacturing, construction, and repairs.

The RENAISSANCE of PHYSICS. By K. K. Darrow. New York, Macmillan Company, 1936. 306 pages, illustrated, 9x6 in., cloth, $3.00. Intended primarily for the layman. Discusses the constitution of matter, transmutation, and other basic questions. Based upon a course of lectures at Lowell Institute.

STATISTICAL YEAR-BOOK of the WORLD POWER CONFERENCE. No. 1. 1933 and 1934. Edited, with an Introduction and Explanatory Text by F. Brown. London, World Power Conference, Central Office; American Committee, Interior Building, Washington, D. C., 1936. 111 pages, tables, 11x9 in., paper, $5.00. Contains statistics of the resources, stocks, imports, exports, and consumption of power and power sources during 1933 and 1934 for all countries for which it was possible to obtain information.

STEAM-ELECTRIC POWER STATIONS. By C. F. John. Scranton, Pa., International Textbook Company, 1936. Illustrated, 8x5 in., leather, $1.50. An elementary descriptive text on power-plant equipment and operation, designed for operating men.

STORM LOADING and STRENGTH of WOOD POLE LINES and a STUDY of WIND GUSTS. By R. H. Sherlock, M. B. Stout, W. G. Dow, J. S. Gault, and R. S. Swinton. University of Michigan, Ann Arbor; sponsored by Edison Electric Institute, New York, 1936. 183 pages, illustrated, 9x6 in., cloth, $2.00 to members; $5.00 to others. Contains information about the wind forces acting against the poles and conductors of a power line during storms, of determining the strength of wood poles under these conditions and of studying the structure of winds during storms.

Die TRANSFORMATOREN. (Die Wechselstromtechnik, edited by I. L. la Cour. Bd. 2.) By I. L. la Cour and K. Faye-Hansen. 3rd edition. Berlin, Julius Springer, 1936. 699 pages, illustrated, 9x6 in., cloth, 48 rm. Discusses the theory, construction, calculation, and operation of transformers.

Engineering Societies Library

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MAINTAINED as a public reference library of engineering and the allied sciences, this library is a co-operative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

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Industrial Notes

General Electric Sales Up.—At the March meeting of the Board of Directors of the General Electric Co. President Gerard Swope announced that orders received for the first two months of 1937 amounted to $64,000,000, an increase of 79 per cent over the corresponding period of last year, and that sales billed in the first two months were $45,000,000, an increase of 39 per cent over the same period last year. Sales billed for 1936 amounted to $268,545,000, compared with $208,733,000 for 1935, an increase of 29 per cent.

Construction Work Gains.—According to F. W. Dodge Corp., the total construction work started in the first two months of 1937 in the 37 eastern states amounted to $431,434,800, a gain of 22 per cent over the corresponding two-months total of $355,211,900 for 1936. Residential building amounted to $141,435,400 or a gain of more than 100 per cent over the total of $68,615,000 for the first two months of 1936. Public works and utilities started during the first two months of 1937 totaled $128,079,200 as against $133,506,200 for the same two months of last year. The decline from last year in this division of the construction industry is entirely due to the slowing-up of the PWA program.

Aerovox Condensers Now Made in Canada.—The control of the former Polymet Delta Co. of Hamilton, Ont., has been taken over by Aerovox Corporation. Henceforth the Canadian plant will operate as Aerovox Canada Limited, producing a line of Aerovox dry and wet electrolytic condensers, also mica and paper condensers, for the Canadian trade. The output will conform with the engineering and production standards of the Brooklyn plant according to S. I. Cole, president of the parent company.

Westinghouse Reports Increased Business.—The annual report for 1936 of the Westinghouse Electric & Mfg. Co. shows orders received amounting to $182,521,304, an increase of 48 per cent over the previous year. Sales billed totaled $154,469,031, an increase of 26 per cent over 1935. Unfilled orders at the end of the year amounted to $48,490,919 compared with $27,137,075 at the end of the previous year.

New Battery Tester.—An instrument for quickly checking the working condition of glass jar type cells used in railway signal service has been developed by the Electric Storage Battery Co., Philadelphia, Pa., termed the Exide "Minute Man." The test is made by discharging the cell at approximately its one minute rated capacity. In this manner the same practical results are obtained as from a 1- or 8-hour-rate discharge test.

New Molding Materials.—Many molded plastic parts, due to the conditions under which they are used, require better resistance to shock or impact than is afforded by general purpose molding materials. In order to meet the varied requirements for impact strength, Bakelite Corp., New York, has developed a new line of Bakelite molding materials which range in impact strength on an A.S.T.M. standard test specimen from 0.22 to 2.0 ft. lbs. energy to break (2.75 to 25 ft. lbs. per inch square). These new molding materials are particularly suitable for handset telephones, instrument cases, junction boxes, and other parts requiring relatively high impact or shock resistance.

Trade Literature

Relays.—Bulletin GEA-2524, 8 pp. Describes undervoltage and phase-rotation relays, type ICR, instantaneous-time delay, for the protection of motors and synchronous converters. General Electric Co., Schenectady, N. Y.

Service Equipment.—Catalog, 96 pp. Describes a wide range of general purpose and safety switches, panels and cabinets, switchcenters, breakers, industrial cable ducts and fittings, etc. Bull Dog Electric Products Co., Detroit, Mich.

Voltage Regulators.—Bulletin 1170B, 36 pp. Describes type AFR automatic feeder voltage regulators. The purpose, construction, and advantages of such equipment, illustrated throughout, are treated at length. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Watthour Meters.—Cat. Sec. 42–215, 16 pp. Describes polyphase watthour meters for house service. Application, construction, performance characteristics, wiring diagrams and ratings for the various available types are included. Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

Motor Generator Sets.—Bulletin 501, 4 pp. Describes and illustrates various types of motor generator sets, built in sizes up to 500 kw and supplied in a variety of combinations. Reliance Electric & Engg. Co., 1086 Ivanhoe Road, Cleveland, O.

Distribution Capacitors.—Bulletin GEA-2494, 20 pp. Describes Pyranol-filled, pole-type distribution capacitors. According to the bulletin, 99.82 per cent of the Pyranol capacitors manufactured in the last 6 years have a perfect operating record. General Electric Co., Schenectady, N. Y.

Building Wires and Cables.—Bulletin BW3, 48 pp. Describes electrical conductors for industrial power and lighting circuits for building of all types; includes tables on wire gauges, formulae for calculating electrical properties of circuits, conversion tables, electrical symbols for architectural plans, etc. General Cable Corp., 420 Lexington Ave., New York.

Noise Meter.—Bulletin, 4 pp. Describes the new type 759-A sound-level meter for measuring noise. Features of the new meter include standardized readings, unusual sensitivity, non-directional pick-up, self-contained and portable, weighing only 23$^{1}/_{2}$ lbs. The new device is very easy to operate and is comparatively low priced. Bulletin 20, a comprehensive manual on noise measurements, is also available. General Radio Co., Cambridge, Mass.

Wiring Survey.—32 pp., "Industrial Guide for Selection of Wire & Cable." A comprehensive, practical treatise on electrical conductors used for industrial purposes and methods of modernizing circuits." Chapters included cover the factors affecting the selection of wire and cables; guide to determining types of insulation; how to use charts; power circuits; standard building wire and cable; flexible cords and cables; control circuits. Anaconda Wire & Cable Co., 25 Broadway, New York City.

Circuit Breakers.—Cat. 6–Sec. 9, 2 pp. Describes a new class TCR-1 indoor, oil-tight circuit breaker with a rating of 75,000 kva interrupting capacity, available in ratings up to 2,000 amperes, 5,000 volts, and for both automatic and non-automatic operation and in both two pole and three pole types. According to the manufacturer there has been no NEMA standard breaker between 50,000 and 100,000 kva interrupting capacity. Roller-Smith Co., 12 Park Pl., New York City.

Wires and Cables.—Bulletin, 4 pp. Describes various types of insulation and coverings; rubber jacketed, lead sheathed and varnished cambric cords and cables, together with weather-proof wire and cable, armored bushed cable, Cresflex, a nonmetallic sheathed cable, parkway cables and special cables. Data on building wire and cable and conduit sizes for rubber-covered building wire are set up in convenient table form for ready reference. Crescent Insulated Wire & Cable Co., Trenton, N. J.

Lubrication Studies.—A series of effectively illustrated, large page booklets entitled "Panorama of Lubrication," described as "an educational series, dedicated to executives, engineers, salesmen and students whose interest in the subject of lubrication demands simplicity." The first three issues of the series, each 24 pages, are now available: 1—The Fundamentals of Lubrication; 2—Lubricating Friction Type Bearings; 3—The Modern Motor Oil. The latter details refining processes and the sources and nature of crude oils. Shell Petroleum Corp., Shell Bldg., St. Louis, Mo.

New Circuit Breaker Feature.—Bulletin 237, 6 pp. Describes the new thermomagnetic overload feature, applicable to all a-c types of I-T-E motor-protecting circuit breakers and available for all types of a-c motors up to 1,000 hp., 550 volts. The new feature discriminates with unfailing accuracy between normal and unsafe overloads. It permits full-voltage starting even when the accelerating period is unusually long and the inertia load exceptionally heavy. The breaker is tripped before dangerous temperatures are reached in a motor or in the device itself. With overcurrents of short-circuit intensity, tripping is instantaneous. I-T-E Circuit Breaker Co., 19th and Hamilton Sts., Philadelphia, Pa.

1,500,000 CM 15 KV KERITE CABLES

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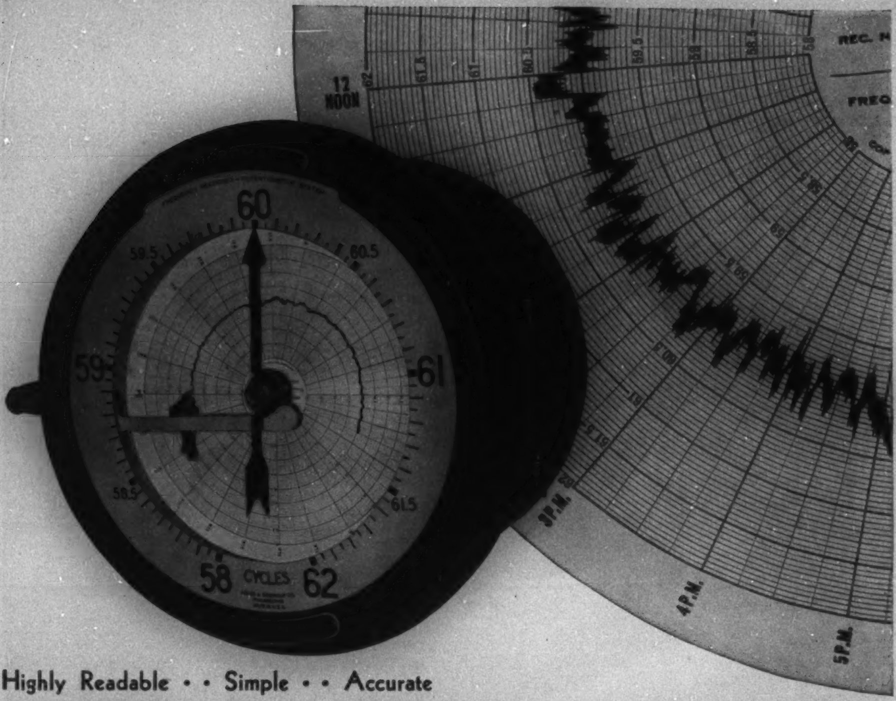
UNION ELECTRIC LIGHT AND POWER CO., ST. LOUIS

INSTALLED 1927

THE KERITE INSULATED WIRE & CABLE COMPANY INC

NEW YORK CHICAGO SAN FRANCISCO



Highly Readable • • Simple • • Accurate

MICROMAX FREQUENCY RECORDER

SYSTEM operators, power-plant operators and industrial-process superintendents are all finding value in the boldness and readability of this new Micromax frequency recorder.

System operators use it to feel the network's pulse, as they direct the generation and interchange of power. Power-plant operators use it to assist in maintaining the constant frequency required both for time-keeping and for driving production machines. Process superintendents find rejects minimized, quality improved and costs cut when synchronous-motored production machines receive constant-frequency electric power and hence travel at highly constant speed.

The Recorder can cover a narrow range such as 59-61 cycles, a wide range such as 55-65 or 115-125, or any intermediate range, such as the 58-62 cycles shown above. In any case, the Recorder's "dial like a town clock," with its 28 inches of calibrated scale, makes the reading easily readable from a considerable distance. The chart, with its overall diameter of 10$^3/_8$ inches, and its calibrated width of 3$^1/_2$ inches, gives adequate record of the important frequency fluctuations. The Recorder can be equipped with signals or alarms if desired.

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THE LAMINATED DISC

- a Duncan Development

IN building watthour meters with two elements acting on a single disc, designers have been confronted with the problem of how to avoid eddy current interference. Duncan solved the problem by ELIMINATING it. Instead of allowing eddy currents to "roam" freely through the disc, Duncan engineers evolved the idea of dividing the disc into segments isolated and insulated from each other. How this disc is fabricated . . . how it works . . . and what advantages it offers are completely described in Bulletin 154 just off the press. Ask your nearest Duncan representative for a copy or write.

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LAFAYETTE, INDIANA

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KILOWATT HOURS
DUNCAN
120 volts

DUNCAN TYPE

IT LICKS
WEATHERING!

Made from Alcoa Aluminum Sheet

Die Cast from Alcoa Aluminum

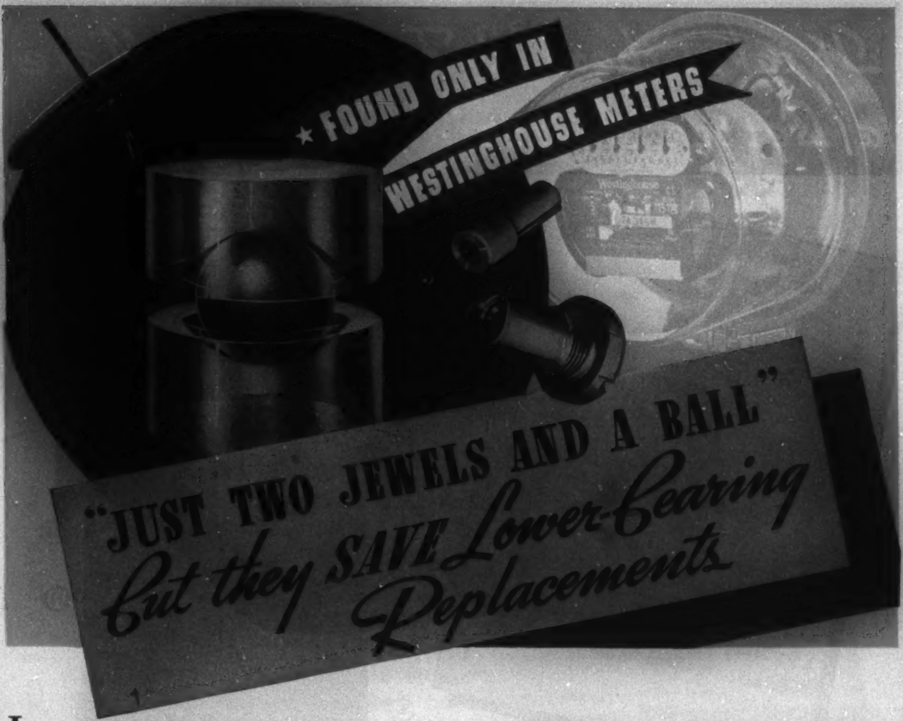
Of course you want your meters outdoors.

Convenience to the consumer . . . protection of consumers against criminals posing as your employees . . . protection to you against current diversion . . . the economy of getting a reading from every trip . . . those are advantages you want.

With cases made of Alcoa Aluminum you get these advantages, and at the same time overcome the problems of weathering. Alcoa Aluminum isn't harmed by exposure. So, no painting . . . no rusted boxes . . . no staining of adjacent walls.

These dollars-and-cents advantages soon return the slightly greater first cost. Manufacturers supply cases pressed from Alcoa Aluminum sheet, or economically die-cast, with intricate fittings, bosses, lugs, and identifying marks produced integral with the original Alcoa Aluminum casting. Would you like to have us send you names of makers? Address ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh, Pennsylvania.

ALCOA ALUMINUM


★ FOUND ONLY IN
WESTINGHOUSE METERS
"JUST TWO JEWELS AND A BALL"
but they SAVE Lower-Bearing Replacements

In 1901, Westinghouse solved the problem of lower-bearing replacements with the invention of the ball and double-jewel bearing. For thirty-five years, this ball bearing has been used in EVERY Westinghouse watthour meter. Not even its style number, 25463, has been changed.

The longer a Westinghouse meter is in service, the more pronounced become the advantages of this bearing. Just two jewels and a ball, but meter test sheets throughout the country definitely prove that they seldom need replacing.

WHY

1 **No form of lubrication is required.**

2 **Rolling contacts between the ball and the two jewels prevent wear—there is no grinding action.**

3 **The action of the ball bearing minimizes jewel breakage caused by jars and vibrations.**

REDUCES MAINTENANCE

Because the ball and double-jewel bearing has almost unlimited life, the time between periodic meter tests need not be restricted by bearing maintenance.

And since this exclusive Westinghouse bearing seldom develops friction, replacement costs are negligible.

Of course, the double-jewel and ball bearing costs more to manufacture, but in no other way can be obtained SUSTAINED ACCURACY and the LOWEST MAINTENANCE COST over long periods of years.

This bearing is just one of those extra values which is expected from Westinghouse . . . *and furnished at no extra cost.*

Ask our meter representative to tell you about the other "extras".

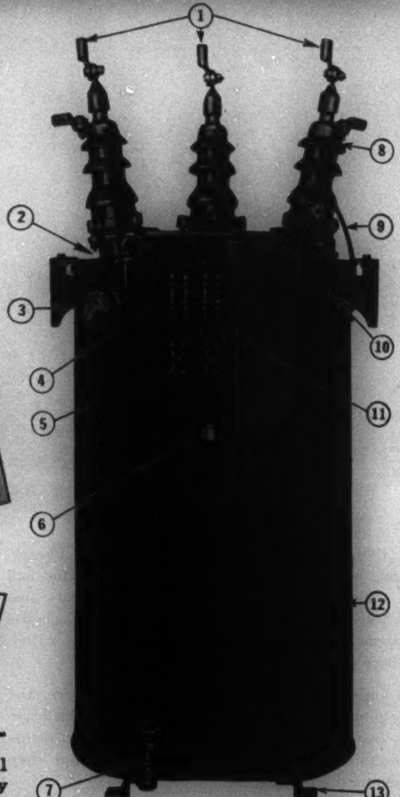
J 40062

Westinghouse

METERS
INSTRUMENTS
RELAYS

It takes these 13 Features to Make a Better Metering Transformer

1. By Pass Protectors supplied for mounting here.
2. Cover Suspended Elements.
3. Magnetic Oil Gauge.
4. Fused Secondary Potential Leads.
5. Secondary Current Switches.
6. Threadless Conduit Connections.
7. Combination Drain Valve and Sampling Device.
8. Co-ordinated Bushings.
9. Potential Ground removable for Megger test.
10. Filter Connection.
11. Hasp for locking Cabinet.
12. Strong Oval Tank—small floor space.
13. Bolting Down Lugs.



Type PCW, 3 Phase, 4 Wire, 60 Cycles, 11950 Volts. Consisting of 3 Potential and 3 Current Transformers

TYPE P·C·W HAS THEM ALL

The ideal equipment for primary metering of rural lines must be highly accurate, compact, easily installed and perfectly reliable.

Allis-Chalmers type PCW, Oil Filled Metering Transformers meet all of these requirements.

TRANSFORMER DIVISION

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MILWAUKEE WISCONSIN

VARNISHED CAMBRIC · RUBBER POWER CABLES · BUILDING WIRE · RADIO WIRES · SINGLE CABLE · FLEXIBLE CORDS · LEAD-ENCASED AND PARKWAY CABLES · ARMORED CABLE

"Boss, you sure took the kinks out of my work when you put

CRESCENT

INSULATED

WIRE and CABLE

on the job!"

These fellows on the job will tell you Crescent products are flexible and tough . . . easy to work and bend without surface cracking. Besides, they are drawn accurately to gauge, annealed to the correct degree of softness and always clean and bright. If you want to cut time and labor costs on installations that must stand up under severe and constant use—you'll do it better with CRESCENT

CRESCENT

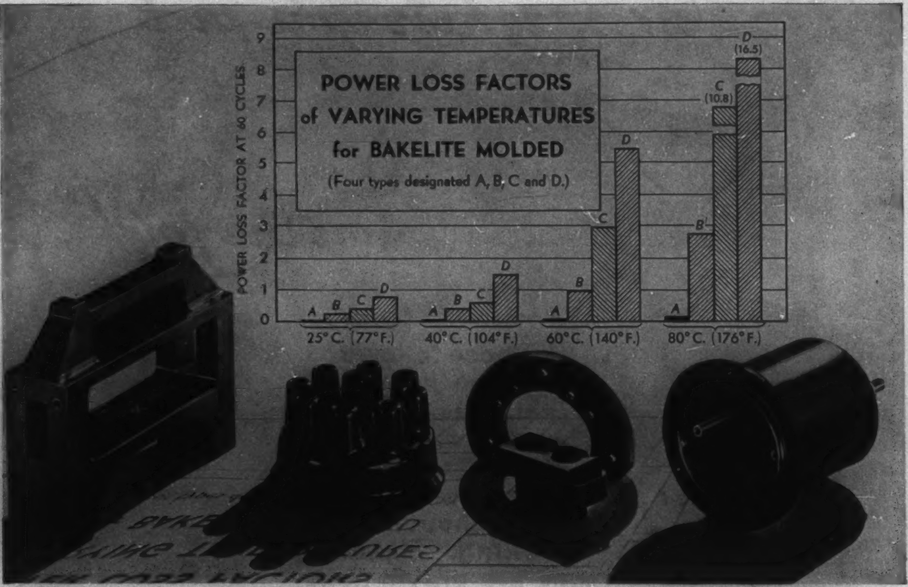
INSULATED WIRE & CABLE CO. INC.

TRENTON, NEW JERSEY

CRESCENT ENDURITE SUPER-AGING INSULATION · WEATHER-PROOF WIRE

CRESFLEX NON-METALLIC SHEATHED CABLE · SERVICE ENTRANCE CABLE · MAGNET WIRE · BARE WIRE

Materials that Solve *Power Loss Problems*



Low-loss applications of different types of Bakelite Molded pictured are: Radio Capacitator Frame, Distributor Head, Motor Contact Strip and Cable Guide, and Frequency Meter Housing.

THERE is growing evidence that power-loss considerations often are important in commercial-frequency electrical products, as well as in radio and electronic devices. In many existing electrical parts, careful study of these losses and of loss-saving materials may lead to significant advances in design.

For all practical frequencies and a wide range of temperatures, there are several types of Bakelite Molded that hold power losses to a minimum. This versatility is indicated in the chart, above, showing 60-cycle characteristics of four different types of the material.

At this frequency and room temperatures, *General Purpose* Bakelite Molded affords practical power economy. At 1,000,000 cycles, a special *Low-Loss* Bakelite Molded possesses a loss-factor of only 14% of the value obtained on the General Purpose Bakelite Molded.

Additional advantages of Bakelite Molded for varied design purposes are its high resistivity, dielectric strength, moisture-proofness, chemical resistance and adaptability of form. Engineers are invited to consult us regarding types of Bakelite Molded best suited to their purposes. Also write for our 48-page booklet 33M, "Bakelite Molded", which gives A. S. T. M. data.

BAKELITE CORPORATION, 247 PARK AVENUE, NEW YORK, N.Y.
BAKELITE CORPORATION OF CANADA, LIMITED, 163 Dufferin Street, Toronto, Ontario, Canada

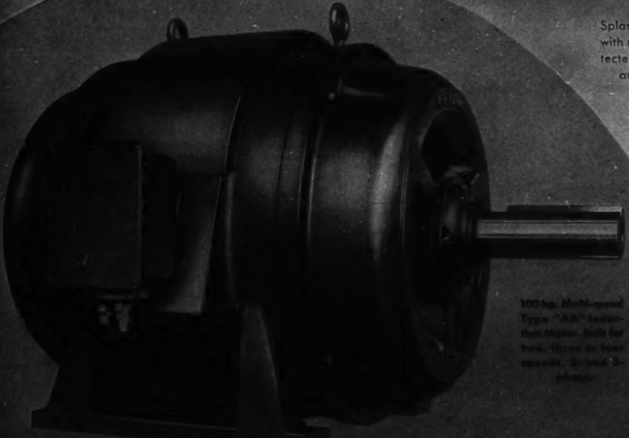
BAKELITE

The registered trade marks shown above distinguish materials manufactured by Bakelite Corporation. Under the capital "B" is the numerical sign for infinity, or unlimited quantity. It symbolizes the infinite number of present and future uses of Bakelite Corporation's products.

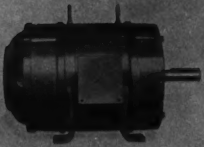
THE MATERIAL OF A THOUSAND USES

Flange-type squirrel-cage motor built with or without feet.

Splash-proof Type "AA" Motor with magnetic brake. Motor is protected against splashing liquids and dirt falling from above.



100 hp. Multi-speed Type "AA" Induction Motor. Built for two, three or four speeds, 2- and 3-phase.



Enclosed, fan-cooled motor designed for high starting torque, low starting current, normal slip. For loads such as mixers, large compressors and conveyors started under load.

SPECIAL-PURPOSE A-c. SQUIRREL-CAGE RELIANCE MOTORS

RELIANCE Squirrel-cage Induction Motors are taking over more jobs every day. They are invading fields of application usually thought of as belonging strictly to direct-current or wound-rotor motors. They are also being supplied in such forms as to do some of their accustomed jobs better.

These improvements in form and operating characteristics are cutting down initial equipment costs, simplifying control and reducing maintenance. The ability to control speeds without gear changes; to start, reverse and stop quickly without clutches, is bringing definite betterments in production and quality in various industries.

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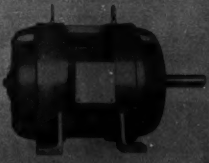
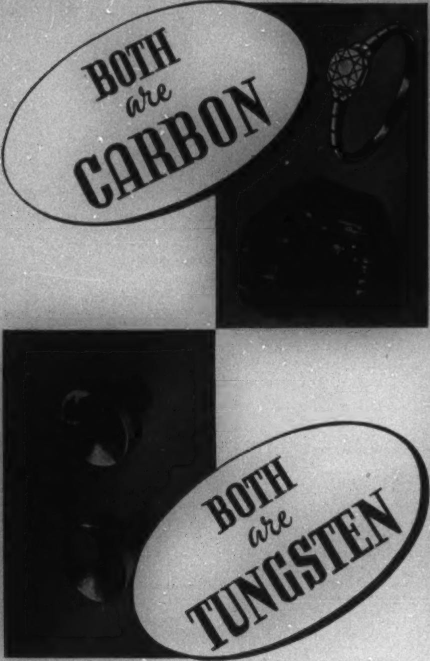
RELIANCE A-C MOTORS

Low-inertia, special-torque fan-cooled motor designed for quick acceleration, quick stopping, frequent and rapid reversing.



Squirrel-cage motor for heavy presses and other flywheel applications. Has high starting torque, low starting current.



Two contacts, both tungsten, yet as different as coal and diamonds. Each is good for a certain purpose, yet when both are tried on the same job, one succeeds, the other fails.

Fansteel makes 9 grades of tungsten of different physical characteristics, and many more grades and alloys of molybdenum, silver and precious metals.

One of these materials is the perfect contact for your product. Turn your contact problem over to Fansteel engineers, who will submit recommendations based upon thorough studies and repeated tests.

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Electrical Contacts

Capacitors

Oil-filled capacitors, hermetically sealed.

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Electrolytic units in all types of cans.

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Both standard and special units for any job.

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Backed by experience second to none.

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And the largest production facilities.

Oil-filled or electrolytic—which do you require? For continuous service use oil. For intermittent starting service, use electrolytic. But in either event, let AEROVOX engineers analyse your problem and recommend the best unit.

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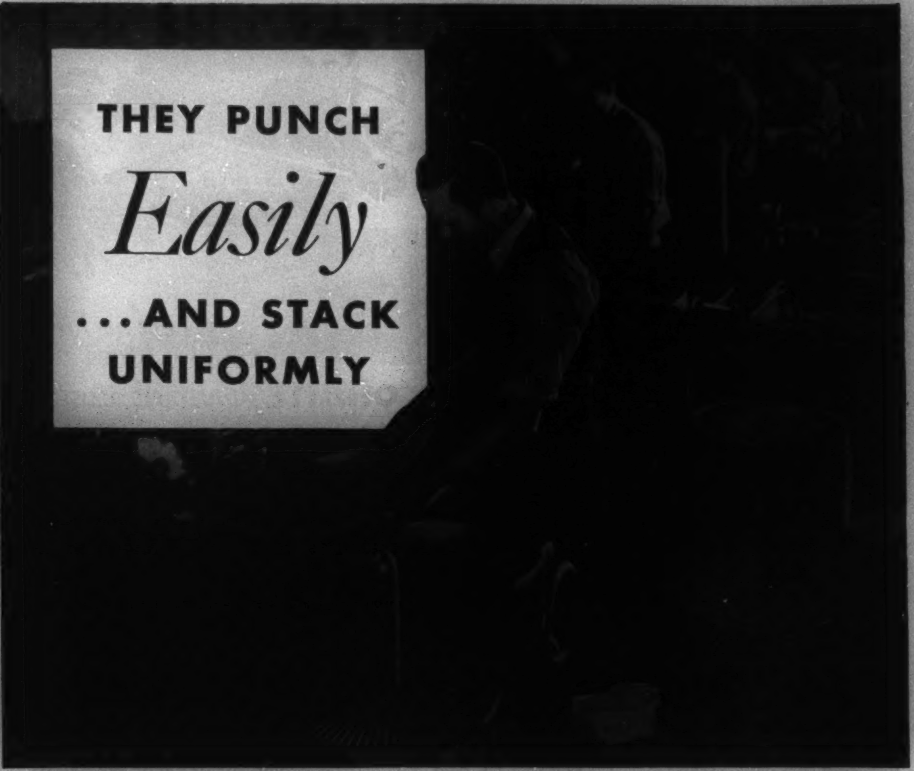

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When YOU buy USS Electrical Steel Sheets you get punchable sheets, whether you specify a high or low percentage of silicon, because our experts keep that end in view—sheets which are *easy on your dies*—sheets which combine *superior flatness* with *minimum brittleness* — sheets which live up to our reputation for *uniformity in quality.*

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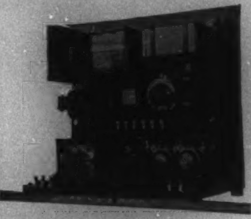
UNITED STATES STEEL



ROLLER-SMITH *announces*

The New Type REF BOOSTER VOLTAGE

REGULATOR

This new device has no moving parts, no moving contacts, no tubes. In fact, it will last a lifetime without any maintenance expense and without any attention.

This Roller-Smith REF BOOSTER VOLTAGE REGULATOR provides a source of constant voltage for many laboratory and production applications such as meter testing, life tests on lamps, instrument calibration, etc.

Available now in 2½, 5 and 7½ KVA sizes.
Send for your copy of Catalog AE-10, Section 1.

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Test it First!
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OHMITE *ADJUSTABLE* RESISTORS

Calculations have their place, but he is a wise engineer who verifies his answers with practical tests. Ohmite "Dividohm" Adjustable Resistors are ideal for this and other applications where a unit whose resistance can be adjusted to various values is desired.

"Dividohms" are wire-wound, vitreous enameled resistors of the very finest construction. A narrow strip is left bare along one side of the unit to make contact with the ball-pointed adjustable lug. A patented percentage-of-resistance scale shows the amount of resistance at a glance. For complete details on this and other Ohmite Resistance Units send for Catalog 16.

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Put your questions up to headquarters for

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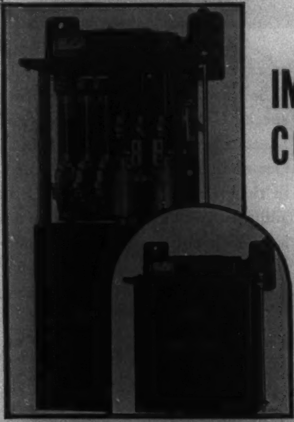

YEARS of experience in the design and construction of Oil Immersed Control have qualified Rowan Engineers to help you in solving your control problems. The illustration shows the combination of starter and disconnect switch with Airseal fuses built as a self-contained unit having many safety features. Information will be gladly sent you upon request.

ROWAN CONTROL
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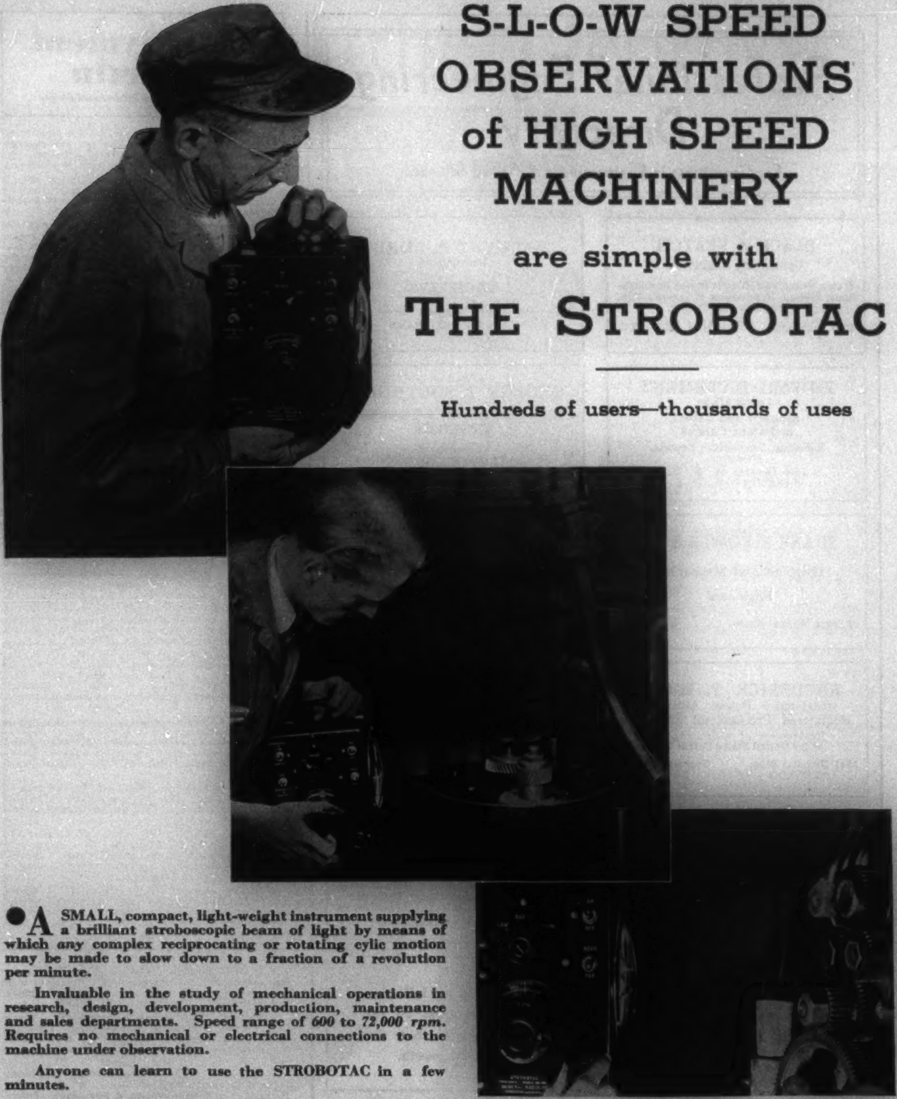

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MAINTAINED for their members by the national societies of civil, mining, mechanical, and electrical engineers, in co-operation with other organizations. An inquiry to any of the three offices will bring full information.

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MIT GRAD, administrative elec engr in the des of large elec machy. Pos desired where knowledge of des and application would be valuable. Exper in negotiating and directing work. E-4.

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E.E., B.S., Cooper Union, 1936, single, 24. Exper in sound recording, radio eqpt. Broadcasting license. Desires junior engg pos in electronics field. Languages: Spanish, German. Location, salary secondary. Available immed. E-5.

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E.E., B.S., '31, M.S. Physics '33, B.S. Indus Ad. '34, expecting Ph.D. Economics '37. Exper pub util engg, research in elec control indus. Age 27. Desires administrative work elec indus. Available June. D-759-8903-Chicago.

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E.E., des, constr, with 16 yrs exper on stations and lines in pub util and indus. E-6.

E.E., B.S., Brooklyn Poly Inst, 1936, Eta Kappa Nu, single, 24. Desires pos with pub util or mfg co of elec eqpt. Location, East. Salary secondary to opportunity. Available immed. E-7.

E.E., Ohio Univ, Carnegie Tech, 1917. Westinghouse tests; 12 yrs U.S. Navy Lab; 7 yrs arc welding des, research, devpmt and applications. Prefers arc welding, procedure control and devpmt. E-8.

E.E., B.S., 1926, NYU Evening, academic honors, thorough shop education; $8^1/_2$ yrs exper lab asst, 3 yrs maintenance of pwr plant. Interested in illumination, transm, machy. E-9.

E.E., B.S., Cooper Union Inst. of Tech, 1935, single, 23; 15 mos exper prod control. Desires elec engg pos with future. E-10.

E.E., M.E.E., 26, married, Cornell, '32. Yr research elec rates, $3^1/_2$ yrs radio transmitter oprn. Desires pos with pub util, engg concern, testg or underwriting lab, East or So. E-11.

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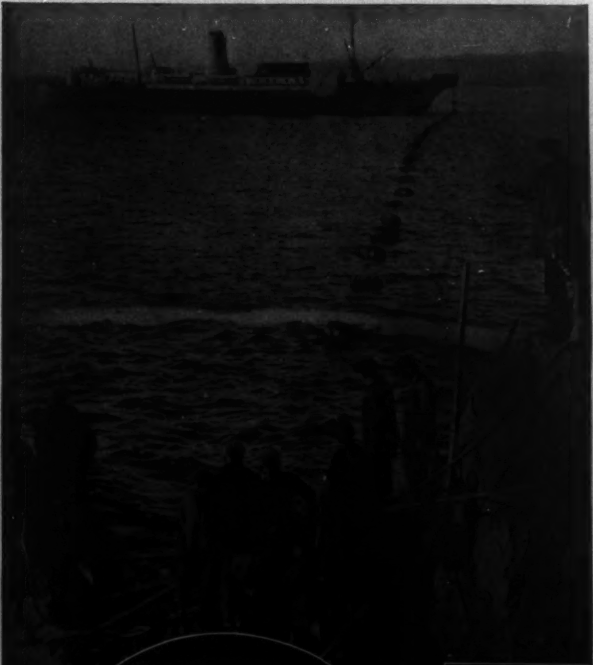

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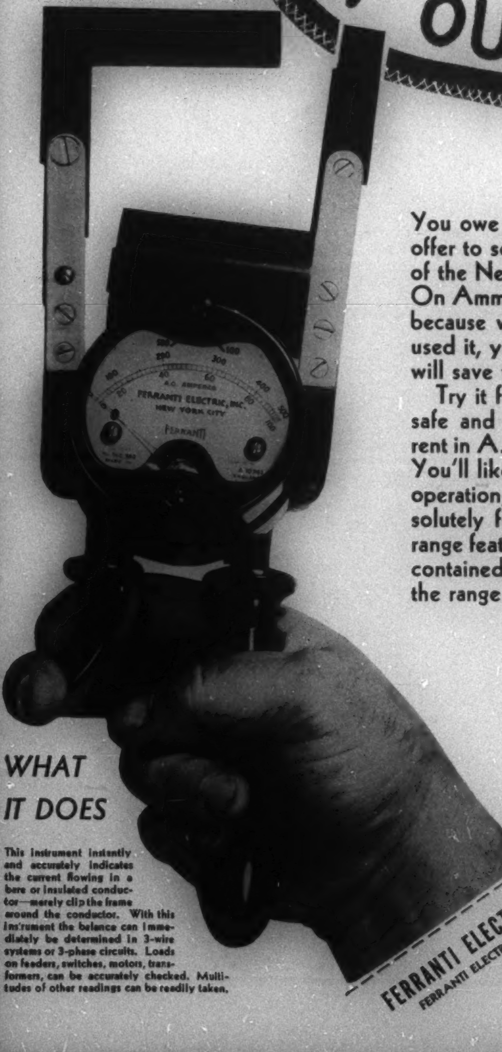

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